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## Notes on Mechanical Drawing.

Prepared for use at the Massachusetts Institute of Technology.

BY

CHARLES L. ADAMS.

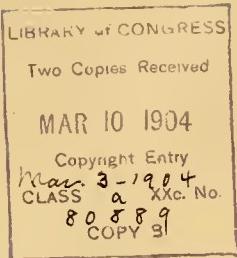
Assistant Professor of Drawing.

CHAPTERS I. AND II.

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BOSTON, MASS.

1904.



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ЧАРЛС АДАМС  
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## INTRODUCTION.

In the construction of mechanical objects, such as buildings, bridges, or machines, or in the making of any of the many things ordinarily produced by the carpenter, machinist, sheet metal worker, or stone-cutter, we distinguish two principal factors. On the one hand we have the designer, or the person who originates, plans, or furnishes the ideas, and on the other hand we have the mechanic, who works out these ideas.

As an example of the relation which must exist between designer and mechanic let us suppose the case of a civil engineer having a commission to build a subway. We may further suppose that he has all information as to route, transportation, etc., and that the preliminary survey and borings have been made. The problem which now arises is purely one of thought and the imagination. Concentrating thought upon the specifications furnished, and the data obtained in the survey and borings, and bringing to bear on these conditions his knowledge of engineering construction, the engineer in due time forms a mental picture of the completed work, and this before any step is taken in the direction of actual construction. Indeed, before this step can be taken it is necessary for the designer to verify his mental picture, to determine all measurements, and to decide upon modes of construction. It is evident that no one man's powers alone are sufficient to foresee and to retain such a multiplicity of facts. At this point, then, it becomes absolutely necessary for the designer to have a means by which he may express the material data and his own ideas. Furthermore, it is evident that this means must be such that it is intelligible not only to the designer himself but to all persons associated with him in the work.

The means which serves these two ends, of formulating the designer's own ideas and of making them intelligible to others, is MECHANICAL DRAWING. It is, in fact, a language,—the language of engineering and the mechanic arts.



## CHAPTER I.

## DRAWING INSTRUMENTS AND MATERIALS.

**I. The Outfit.** The usual instruments and materials for line drawing are shown in Plates 1 and 2. Several special instruments and materials for brush-work are given in Plate 3.

Having read Articles 2 to 17, first-year Institute students should procure the following :—

1 Set of Instruments.

2 Drawing-Boards,  $11\frac{1}{4}$  x  $15\frac{3}{4}$  ins. and  $17 \times 22\frac{1}{2}$  ins.

2 T-Squares, 15-inch, and 21-inch fixed head.

Rubber, or Amber triangles as follows :—

1  $45^{\circ}-45^{\circ}$ , 4-inch.

1  $45^{\circ}-45^{\circ}$ , 8 "

1  $30^{\circ}-60^{\circ}$ , 5 "

1  $30^{\circ}-60^{\circ}$ , 10 "

2 Irregular curves (of the shapes shown in Plate 2).

1 Twelve-inch Architect's Triangular Scale (divided into sixteenths of an inch, and scales of  $\frac{3}{32}$ ,  $\frac{3}{16}$ ,  $\frac{1}{8}$ ,  $\frac{1}{4}$ ,  $\frac{3}{8}$ ,  $\frac{1}{2}$ ,  $\frac{3}{4}$ , 1,  $1\frac{1}{2}$ , and 3 ins. to a foot).

1 Pricker.

3 "Koh-i-noor" Pencils, H, HHH, and HHHHHH.

1 HHHHHH "Koh-i-noor" Lead (for the compasses).

1 Dozen Thumb-tacks.

Drawing-papers (in a strong envelope,  $17 \times 22\frac{1}{2}$  ins.) as follows :—

6 Sheets Whatman's Half Imperial, Cold Pressed.

6 " " " " Hot "

6 " Duplex Detail Paper (cut half imperial size).

2 " Imperial Tracing cloth " " "

1 Sheet Rowney's Roll Tracing Paper (cut half imperial size).

1 Block of White Practice Paper, 11 x 15 ins., 24 sheets.

1 Faber's Emerald Rubber.

1 Stick India Ink, super-super, half size.

1 Fine File, or Sand-paper Pad (for sharpening pencils).

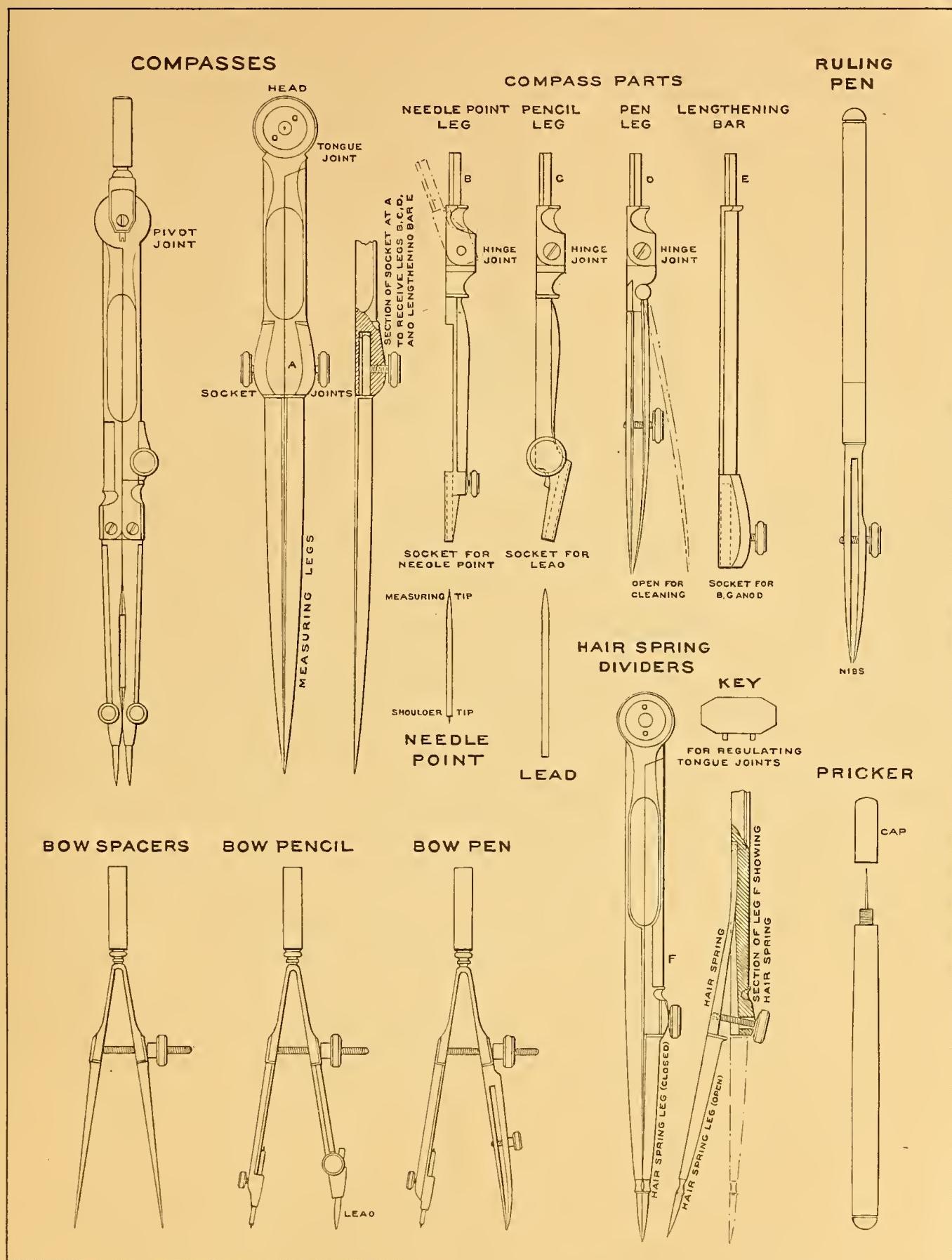
1 Slate Ink Slab, with cover.

1 Steel Eraser.

- 1 Sand-rubber, Faber's, small.
- 1 Agate Burnisher.
- 1 Piece Chamois Skin, size about 10 x 12 ins.
- 1 Fine Oil Stone, 3 inch (for sharpening right-line pens).
- 1 Penholder and Pens,—  $\frac{1}{2}$  doz. each of Gillott's 303, and D. Leonard & Co.  
Ball Point, 521 F.
- 2 Camel-hair Brushes (of the sizes shown in Plate 3).
- 1 Water Glass, and Tumbler (each of the size given in Plate 3).
- 1 Medium-sized Sponge.
- 1 3-oz. Jar Higgins' Drawing-board Paste.

If possible the beginner should entrust the purchase of his drawing outfit to an experienced draftsman, but if this is impracticable he should deal directly with some one of the well-known firms who make a specialty of drafting instruments and supplies, and stand ready to make good any defect found within a reasonable time.

Plate 1.





**Plate 2.**

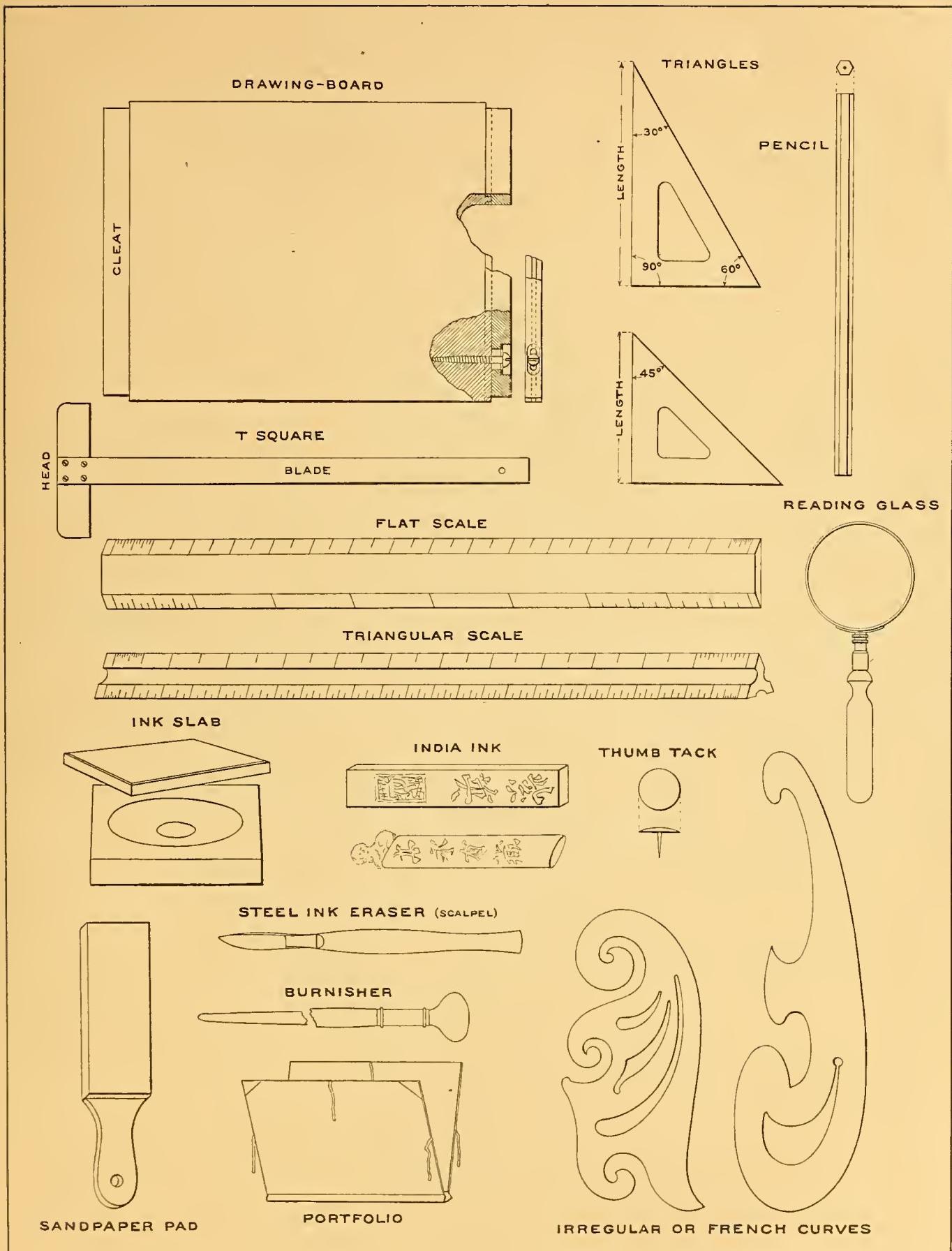
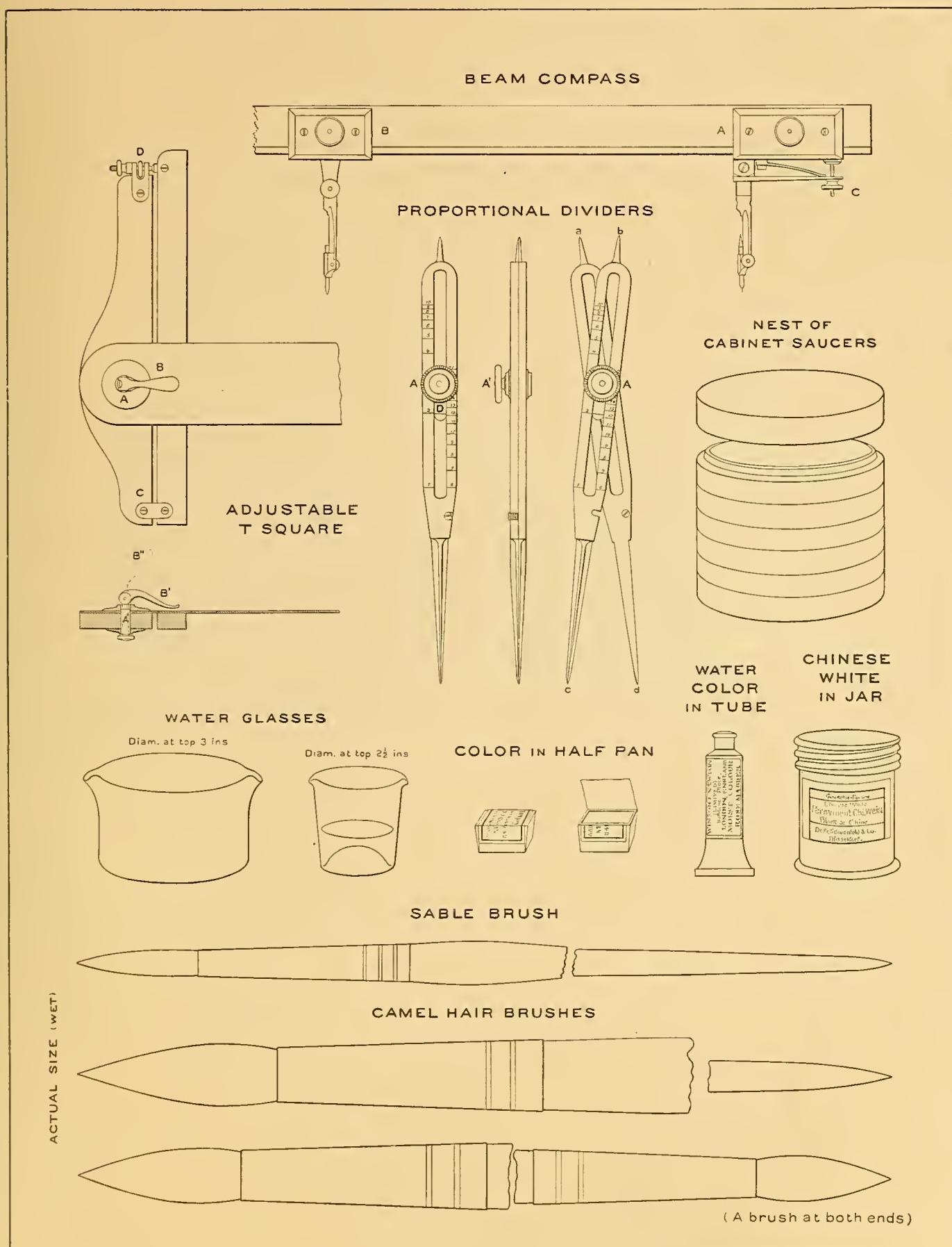




Plate 3.





**2. Instruments.** Elaborate sets of instruments are unnecessary and the purchase of special instruments may be deferred until they are needed. If the student's means will permit he should get the very best instruments, otherwise

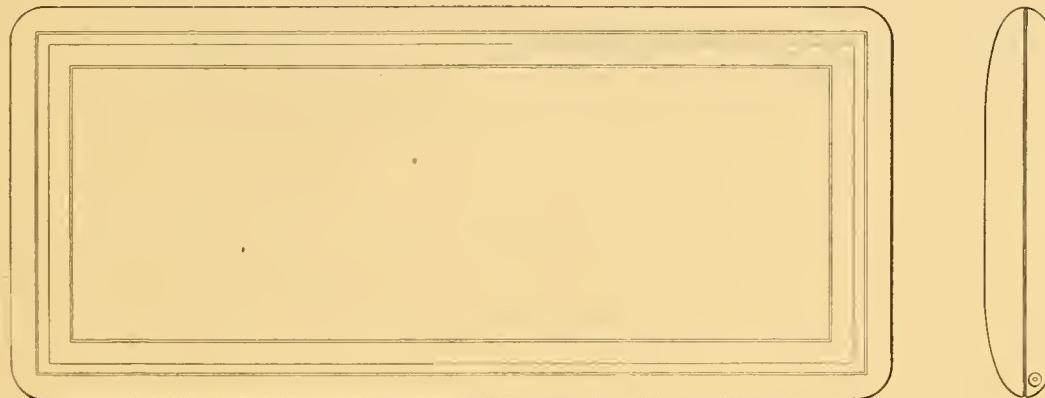
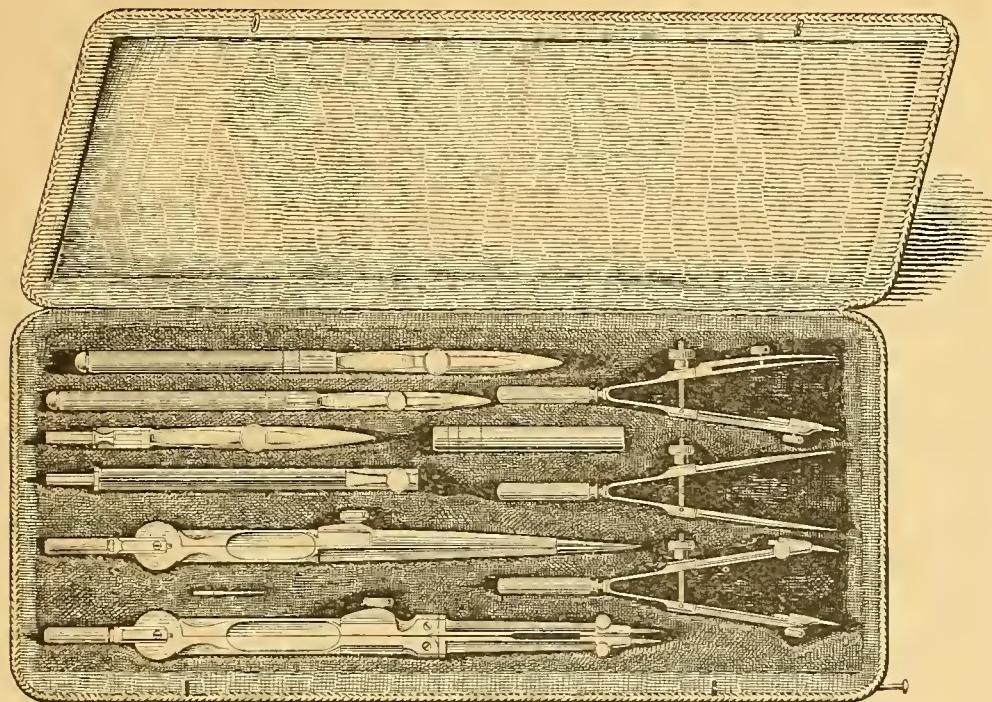


Fig. 1.

he cannot obtain the best results in his drawing. Moreover, besides obviating vexatious incidents attendant upon the use of cheap instruments the best, with proper care, will work satisfactorily for years.

Instruments in cases\* are shown in Figs. 1 and 2. An excellent set, Fig. 1, includes some one of the higher grade imitations of the Alteneder compass, and hair-spring dividers, with genuine Alteneder ruling pens and

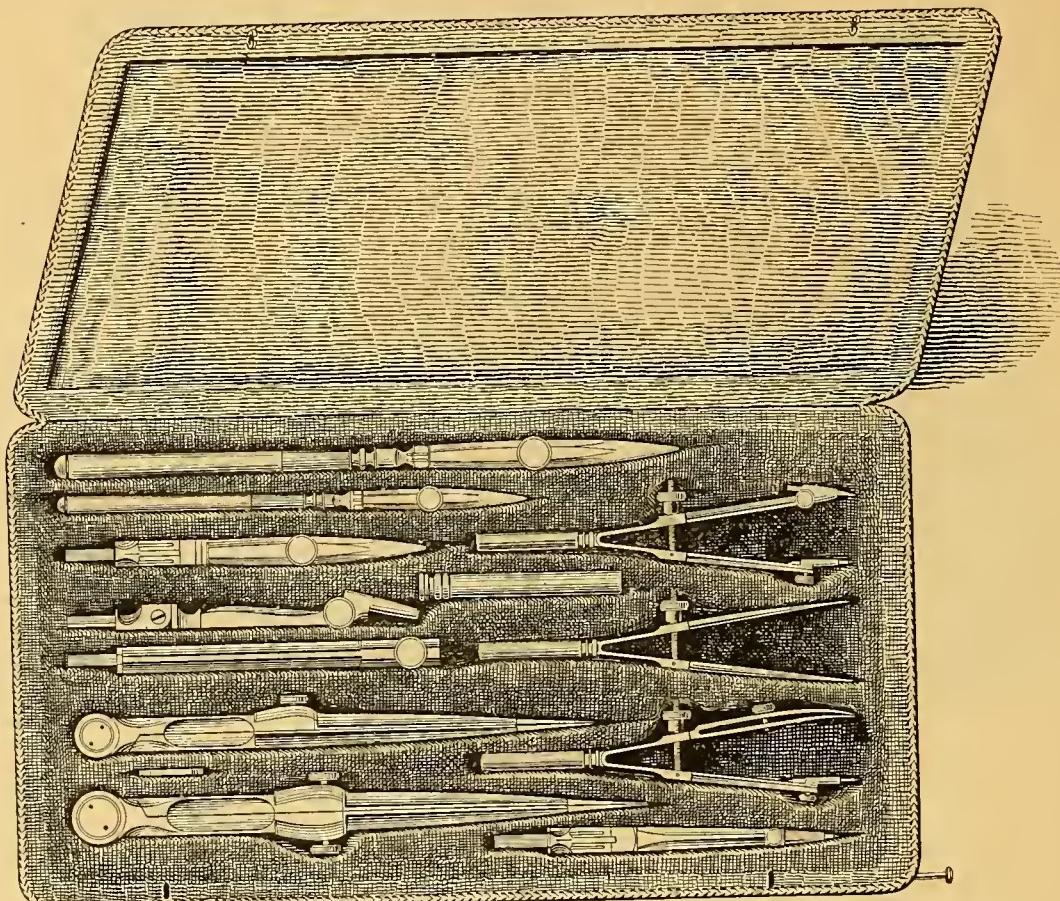


Fig. 2.

bows. Price (1903) should be in the vicinity of fifteen dollars. If the student cares to pay the difference in price, he is strongly advised to have the compass which comes with the regular sets changed for one having a hair-spring adjustment similar to that shown in the next to the last cut, Plate II.

A minimum priced set (about eight dollars) with which good results can be obtained is shown in Fig. 2. Although the pivot-joint instruments and the Alteneder style pens are rapidly taking the place of the tongue-joint instruments and hinged-nib pen, Fig. 2, the latter are here given as they still appear in

\* A more recent style of case is the folding pocket case with flaps.

the dealers' catalogues. The pivot-joint instruments of the same quality as the tongue-joint ones are usually supplied at the same price.

A device, Fig. 3, for carrying instruments in the pocket is sometimes preferred to a case, and may be made by the student. It is of chamois leather, — cloth-bound on the edges if desired, — and is fitted with pockets, of the same material, for the reception of the instruments.

**3. The Drawing-board.** It should be of straight-grained, well-seasoned white pine, free from sap places and knots and neither shellacked nor varnished. The cleats should be of the same wood, tongued and grooved, and screwed to the board (never glued). The outer edge of each cleat should be perfectly straight and the grain of the wood parallel to the edge of the cleat. Ask the dealer for a steel straight-edge and with it test the straightness of the working-edge of the board. If a straight-edge is not at hand test for straightness by this method : (a) Let  $AB$  be any edge to be tested. With  $AB$  used as a ruler draw a very narrow pencil line. Reverse  $AB$ , end for end, rule again, and if  $AB$  is perfect, the two pencil lines will coincide. The metal edge sometimes attached to small drawing-boards is altogether unsatisfactory. To provide for the contraction and expansion of the board, due to atmospheric changes, the screws should pass through slots in the cleat, having a width equal to the diameter of the screw. (See the drawing-board, Plate 2.) With this arrangement the board is less liable to warp, or split, since, while the heads of the screws have sufficient bearing to hold the cleats in place, the slots permit the screws to slide when working back and forth with the expansion and contraction of the board.

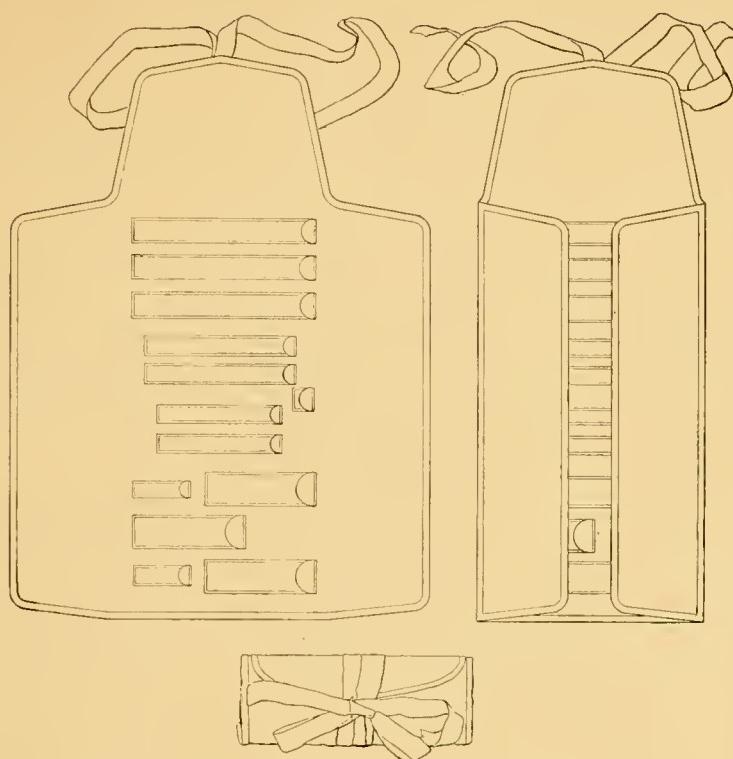


Fig. 3.

**4. The T-square.** The usual T-square is made of pear wood. A better one has the so-called ebony-lined blade. For greatest accuracy a steel T-square, and a special steel edge for the drawing-board are necessary; but it tends to soil the paper and to smear the dry ink lines. In choosing the T-square, see that the blade is wholly free from nicks and that the grain is straight and parallel to the edge of the blade. Test the straightness of the T-square blade, and head either according to (*a*) Art. 3, or by placing each of these edges against a steel straight-edge, held between the eye and the light. The edges should be in close contact throughout.

**5. The Triangles.** These are made in wood, hard rubber, and amber respectively. The rubber, and the amber triangles are more accurate than those of wood; the amber is less likely to soil the drawing than the hard rubber, and also permits the lines of the drawing to be seen through the triangle,—often a decided convenience. In selecting the triangles see that each one is not warped, by sighting across its surface.

To test for "squareness," place the triangle *A*, Figure 4, on a straight edge, and with a very sharp pencil draw an accurate line along edge *a b*. If, when the triangle is reversed (as at *A'*) edge *a b* does not coincide with the ruled line the triangle is not "square."

To test for the straightness of the edges proceed according to (*a*) Art. 3, or, holding them between the eye and the light, place two triangles edge to edge, or each against a steel straight-edge, and see whether they are in close contact throughout.

**6. The Scale.** Besides observing whether the scale is perfectly straight and free from nicks, see that all edges are thin and sharp, and that the graduations are very narrow, clear-cut lines. Blunt edges and muddy graduations seriously interfere with accuracy in the laying off of measurements.

**7. Drawing-Papers.** The best paper for finished drawing is made by J. Whatman. It comes in sheets, has various weights and sizes, and is finished in three different styles of surface: hot-pressed, cold-pressed, and rough. The hot-pressed has a smooth surface suitable for pencil and fine-line drawings.

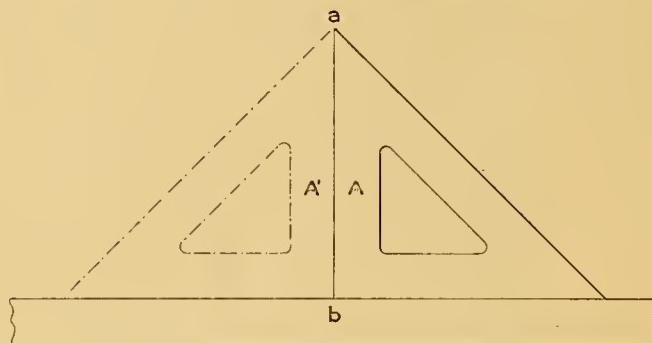


Fig. 4.

The cold-pressed has a grained, somewhat rough surface which takes well both ink line and washes of India ink and color. The rough has a coarsely grained surface adapted for bold architectural and water-color rendering. All of these surfaces stand erasures well. An excellent paper for office and shop drawing is the duplex: it takes well both pencil and ink lines, and stands erasers, and handling. It comes in two tints, cream and drab, is sold in sheets, by the yard, or in ten yard rolls, and has widths of 30, 36, 42, 56 and 62 inches. Useful for practice work and cheaper than the preceding are the German papers, their American imitations, and manila paper.

Standard sizes of drawing papers are as follows:

Cap, 13 x 17 ins.	Imperial, 22 x 30 ins.
Demy, 15 x 17 ins.	Elephant, 23 x 28 ins.
Medium, 17 x 22 ins.	Columbia, 23 x 34 ins.
Royal, 19 x 24 ins.	Altas, 26 x 34 ins.
Super-Royal, 19 x 27 ins.	Double Elephant, 27 x 40 ins.
Antiquarian, 21 x 53 ins.	

8. **The Pricker** is used for laying off measurements and noting points in the drawing. A good substitute for the commercial article, shown in Plate 2, can easily be made thus: Whittle out of straight-grained, soft wood a handle about  $3\frac{1}{2}$  ins. long and tapering from  $\frac{1}{8}$  in. to  $\frac{3}{16}$  in. diameter. Break off the eye of a No. 9 sewing needle with a pair of pincers, push the point of the needle into the smaller end of the handle, taking care to keep the needle accurately in line with the axis of the handle. When it has been pushed in say three-fourths of its length, draw it out, reverse it, and force it, broken end first, into the hole already made in the handle. The needle should project  $\frac{3}{8}$  in.

9. **The Pencils.** The commercial pencil sold for writing purposes is wholly unfit for mechanical drawing; only the best should be procured, and in the hexagonal style. The following makes are preferred by draftsmen: Dixon (American) L. and C. Hardtmuth, E. Faber, Johann Faber, and A. W. Faber (all imported).

10. **The Pencil Sharpener.** A small, fine-cut file is often used for sharpening pencil and compass leads, but it soon becomes clogged with the lead. A convenient and inexpensive substitute is the sandpaper pad (see Plate 2), a block of fine sandpaper fastened to a strip of wood. When a sheet of the pad is used, it is removed to expose a fresh one. A piece of fine sand-paper, or emery cloth fastened to a strip of wood, say  $6 \times 1\frac{1}{2} \times \frac{3}{16}$  ins. will do very well.

**11. The Thumb-tacks.** Tacks costing from five to twenty cents a dozen are sufficiently good. Small copper tacks (not iron ones) are sometimes used. The shank of the thumb-tack should be slender, the points very sharp and the head thin, the upper or curved surface intersecting the lower or plane surface in a sharp outline, that it may not catch the edge of the T-square blade. The shank should be so fastened to the head that, when pressed into the drawing-board, it will not push through the head into one's thumb. Steel tacks which have the points stamped out of the head are good in this respect; they are also easily withdrawn with the finger nail, but the edge of the head is rather thick.

**12. The Rubber Eraser.** Select a piece of rubber that is soft and pliable. For cleaning inked drawings the sponge rubber is best for large areas; the kneaded, or velvet rubber for cleaning around and between the lines.

**13. The India Ink.** The best ink gives a glistening, black line and is satisfactory for brush work; while lines made with cheap inks are apt to look dead, tend to smear easily, and are unsuitable for brush work. A stick, half-size, at fifty cents, is the cheapest that should be considered.

**14. The Steel Ink Eraser.** A surgeon's scalpel is recommended, as the steel is far superior to that in ink erasers usually found at the stationers. Length should be about  $5\frac{1}{2}$  ins., and the shape as shown in Plate 2.

**15. The Burnisher.** The cut, Plate 2, shows one of the various styles of agate burnishers. The instrument is used after an erasure of ink-lines, to prepare the paper for the re-inking of lines.

**16. The Brushes.** The best brushes for wash drawings are Winsor and Newton's Sables. As these in large sizes are expensive, camel-hair brushes are frequently used instead. Japanese brushes are inexpensive and excellent. All brushes should be tried in water at the time of purchase. When filled with water and passed quickly downward, across the edge of the glass, the brush should recover to form a sharp point. The snappier the movement on the hair the better the brush.

#### THE USE AND HANDLING OF THE INSTRUMENTS.

**17.** Before speaking of the instruments in detail we may call the reader's attention to several general points. On beginning actual drawing the student should remember that he is beginning the study of a language, and a practical one (see Introduction). He, therefore, should not look upon his work merely as a school requirement, or as concerning him only for the time being, but as a necessity if he purposes to become a draftsman, an engineer, or an architect.

## THE USE AND MANIPULATION OF THE INSTRUMENTS.

17. Before speaking of the instruments in detail we wish to call attention to several general points. The reader should remember that he is taking up the study of a language, and a practical one (see Introduction). In order that he may learn the more quickly to use this language effectively, he should imagine that the processes and ideas presented in the instruction are in reality his own,—that they spring from within himself,—in order that he may always feel, when drawing, that he is expressing some thought, or idea which is distinctly his own. By so doing he learns to think for himself, and in the language of drawing. Furthermore, he should not look upon his work merely as a school requirement, or as concerning him only for the time being, but as absolutely indispensable if he purposes to become a draftsman, an engineer, or an architect. If he intends to follow other lines, he should know that, as affecting all scientific work, mechanical drawing is an effective means for acquiring precision of manual execution, of observation, and of thought.

Regarding the working or practical side of drawing, it should be understood that the methods here presented are not the only ones which exist, and that draftsmen often differ in their ideas of the way in which a thing should be done. The traditions, and the character of the work of a particular office often influence the methods of the draftsman. A beginner, however, should take pains to carry out instructions literally and in the best of faith, until, having learned to work according to one method, he reaches a point where he is competent to judge of others.

Concerning one's self, the advantage of workmanlike habits should be kept in mind. Avoid lounging on the drawing-table, and like lazy habits. An erect position at the drawing-table, and quiet, brisk attention to the work in hand are not only suggestive of one's general quality, but are conducive to better results in drawing; while the former is also important from the standpoint of health. The care of the instruments, of the drawings,—finished and under way,—and of the drawing-papers, demand proper attention. It is worth while also to have an eye to the orderly arrangement of things on the drawing-table, and to leave everything in order on stopping work.

18. **Examination of the Outfit.** The student should now get together his instruments and materials and become familiar with them through comparison with Plates 1, 2, and 3. The remarks on these Plates should be noted and the names memorized.

**19. The Care of the Instruments and Materials.** The instruments should be kept clean, free from moisture, and always in good working order. The pens should be sharpened properly and should not be allowed to become clogged with ink. The joints of the compasses should be regulated to work freely, neither loose nor stiff. A trifling quantity of oil may be used on the regulating screws of the pens and bow instruments, if these do not turn easily. Leads that are too short, and needle-points that have become blunted should not be used in the compass, and bow-pencil. When the instruments are not in use, the tension of all springs should be released; that is, the bow-instruments, and the blades of the pens

should be left open (*A*, Fig. 5). In opening and closing the bows, pinch the legs together with the fingers,—so that the pressure will be taken off the regulating nut (*A*, Fig. 6),—turn the nut, and then let the leg spring gently back against it. When the instruments are not to be used for a considerable time, they should be rubbed with a slightly oiled rag.



Fig. 5.

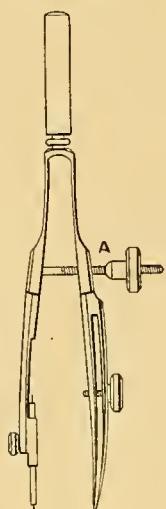


Fig. 6.

Regarding materials, a drawing-board is less likely to warp when stood on edge, so that the air may circulate about it, than when left lying flat. If a drawing-board is re-planed to remove dents, it should be planed on both sides, since it is more likely to warp if planed only on one side. It is best to keep the T-square and triangles hung up, when not in use, away from sunlight and heating apparatus. The working-edge of the drawing-board, the head of the T-square, and the T-square blade should be tested (Arts. 3 and 4) from time to time, and if found inaccurate should be trued. Drawing-papers should be kept flat. The stick of India ink should be wiped perfectly dry after being used, otherwise it will crack, or crumble. Liquid ink should be kept covered to prevent thickening and to keep out dust.

**20. Precision and Speed in Drawing.** The accuracy with which a drawing need be made depends upon the purpose it is to serve. For example, the graphical solution of problems in certain machine and engineering drawing calls for the strictest accuracy. In a construction or working drawing,—one having measurements lettered on it,—it is usually necessary to be only fairly accurate. In certain architectural drawing a very free treatment is the most satisfactory. At the outset, however, every student, whatever the character of his prospective

work in drawing, should strive for strict accuracy ; not until he has learned the full meaning of precision, and acquired the power to work accordingly, should he turn his attention to free methods.

At the same time the question of speed must be considered. In general, as compared with free treatment, precision of execution implies diminished speed. It does not follow, however, that in order to obtain precise results it is necessary to work slowly ; from the start there should be sustained effort to combine both accuracy and speed. To accomplish this requires knowledge of methods, and judgment in their use. Moreover, it is evident that due care is necessary for precision, and brisk execution for speed ; but fussiness must not be mistaken for due care, nor mere bustle for speed. The question of speed is largely one of the use of wits, in adopting direct and labor-saving methods, rather than one of quickness of hand.



Fig. 7.

**21. The Line of Sight in Execution.** As affecting precision, it is important always to keep in mind the position of the eye relatively to all parts of the drawing, and to the instrument in use at the time. To secure the best results, each portion of the drawing, when observed, should lie in a plane perpendicular to the line of sight. Thus in viewing the drawing-paper,

Fig. 7, in the vicinity of *B*, the plane of the paper *DEF* should be perpendicular to the line of sight *AB*. Therefore, in order to satisfy this condition as fully as possible, the draftsman should work standing, that he may easily move about so his line of sight will always be perpendicular to the paper for each observed portion of the drawing. To the same end, if sitting, he should remember, when

passing from one part of a drawing to another, to change the position of the board. A block to incline the drawing-board is convenient.



Fig. 8.

In ruling lines, the draftsman's head should move with the ruling-point. If the head remains in a fixed position and only the eye follows the ruling-point, it is evident that, as the point moves away from the eye, the angle which the line of sight makes with the paper constantly decreases; at the same time the chance of error increases. Also, in ruling, the eye should see the line of contact of ruler and paper; to meet this condition it is evident that the line of sight cannot remain perpendicular to the paper, but angle  $BAC$ , Fig. 7,

should be kept as small as possible. In laying off measurements from the scale, the line of sight should be as nearly perpendicular to the paper as possible at the particular division on the scale which is to be laid off; that is, angle

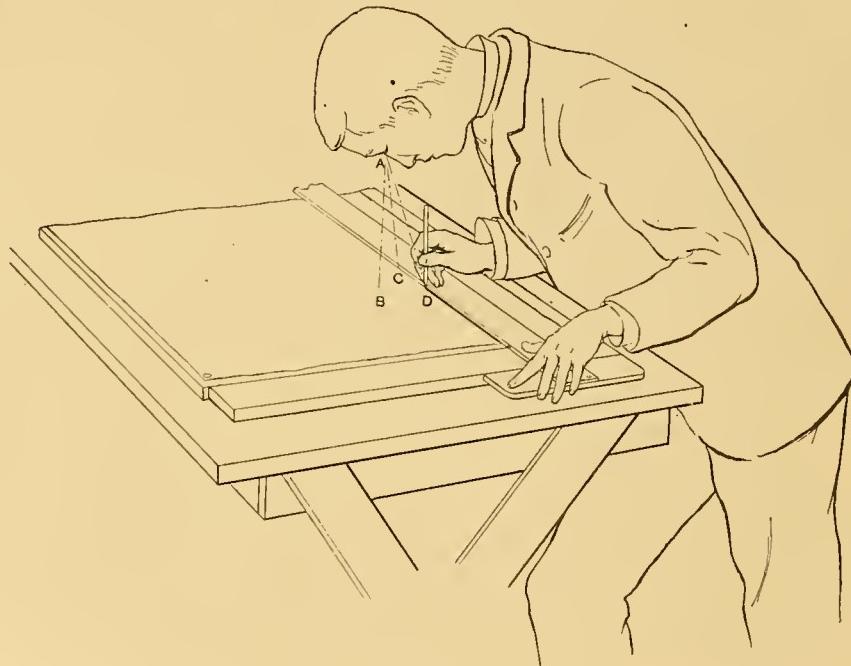


Fig. 9.

$BAC$ , or  $BAD$ , Fig. 8, should be no greater than is necessary to bring into view the point of the pricker, or pencil.

For lines longer than, say 12 ins., ruling should be done standing and as shown in Fig. 9. The draftsman stands facing the drawing and with the left side of the body turned toward it. Leaning over the drawing, the line of sight,  $AC$ , is directed slightly forward and inward from perpendicular  $AB$  to the paper; forward, in order to see in advance of the moving point  $D$ , and inward, to see distinctly the line of contact of the ruler and the paper. If a line to be ruled is a long one, the body should face in the direction of the required line, to permit the draftsman to walk forward easily in following the hand. This method insures greater accuracy in stopping a line at a given point.

**22. Testing.** The habit of frequently checking, or testing a drawing is the surest way to secure accuracy. In professional practice it is the only safeguard against costly mistakes.

This subject is fully presented in connection with the exercises.

Having pointed out the foregoing features of the general subject, we now take up details necessary to prepare the way for the first exercise in drawing.

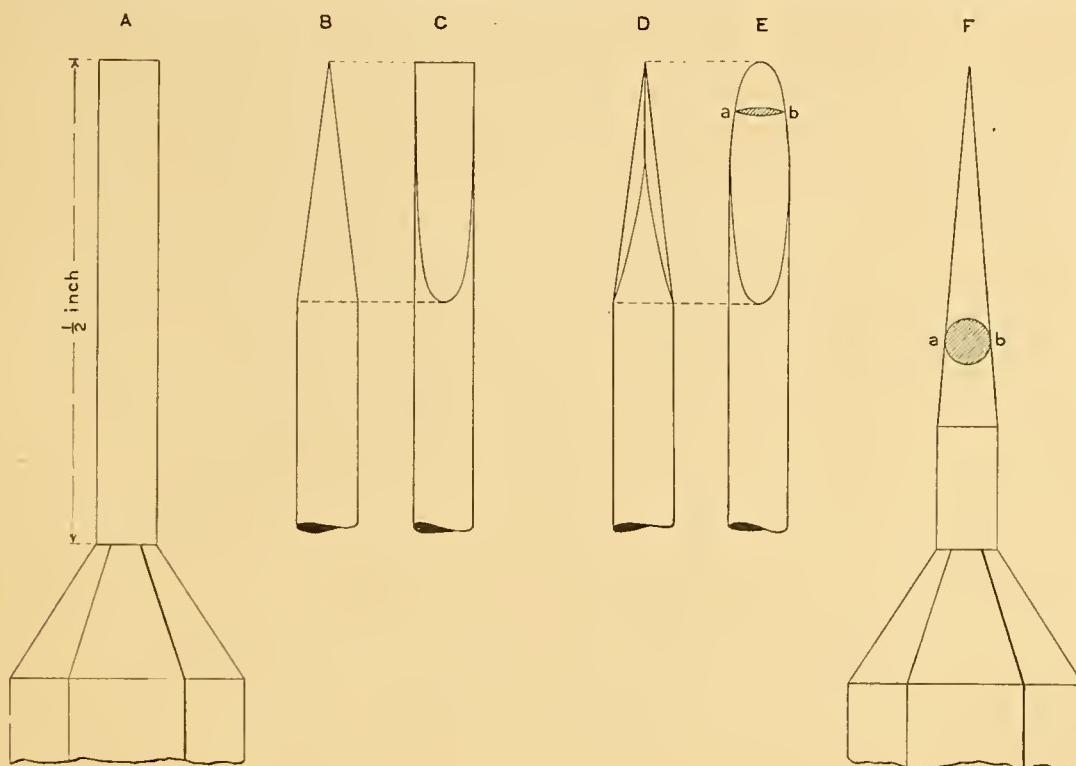


Fig. 10.

**23. The Sharpening of Pencils and Compass Leads. (a) The ruling-point.**

Cut away the wood of the 6 H pencil to expose at least half an inch of the lead (*A*, Fig. 10).

With the file or sandpaper pad resting on something solid, as the edge of the drawing-table, and with the forefinger on the wood where it meets the lead

(Fig. 11), press the lead lightly but firmly against the sandpaper, and with a steady back-and-forth motion grind opposite sides of the lead to form an accurate wedge (see edge view *B* and side view *C*, Fig. 10). Next, holding the pencil as in Fig. 12, carry it very lightly back and forth, and with each separate stroke slightly rotate the pencil about its axis in the opposite direction to that of the stroke. This rocking motion forms the finished point (*D* and *E*, Fig. 10). It will be noted that, seen sideways, the contour of the point is elliptical (*E*, Fig. 10); a cross section of the point gives the form shown at *ab*, *E*, Fig. 10. The advantage of this point is that, by slightly changing the

angle of the pencil, when ruling, the draftsman may obtain a succession of sharp points.

Another ruling point sometimes used is formed by first making a conical point (*F*, Fig. 10) and then grinding its opposite sides to form a wedge.

(b) *The measuring-point.* For this point, which is often used instead of the pricker, to lay off measurements from the scale, the pencil is worked to a slender and extremely sharp conical point (*F*, Fig. 10). When forming this point, carry the lead back and forth on the sandpaper, meanwhile constantly rotating the pencil about its axis.

It is convenient to sharpen the opposite ends of the same pencil for the ruling and the measuring points.

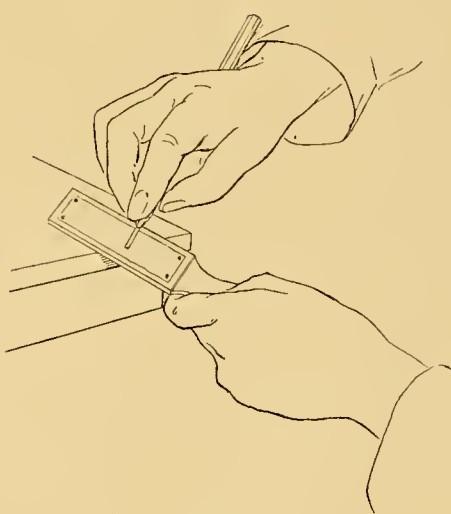


Fig. 11.

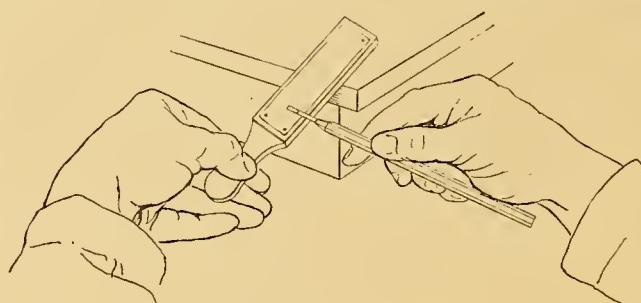


Fig. 12.

(c) *The sketching-point.* This point is used for putting in an occasional free-hand line on the mechanical drawing, for sketching in lettering, writing on the drawing, etc. It should be conical in form, less slender than F, Fig. 10, and only fairly sharp. For this purpose an H, or HH pencil should be used.

(d) *Compass leads.* The leads for the compass, and bow-compass should be placed in the sockets of these instruments and then sharpened. Let the lead extend well beyond the socket of the instrument, that the latter may not come in contact with the sandpaper. Form the point according to the directions for forming a ruling-point (*a*, Art. 23). When sharpened, the lead should be adjusted in the socket as shown in Figs. 13 and 14. It will be seen that, when the legs of the compass are closed (Fig. 13), — the needle-point projecting about  $\frac{3}{8}$  inch beyond its socket, — the needle should project slightly beyond the tip of the lead (see the distance in Fig. 13). When the compass is open (Fig. 14), the plane *ab* of the lead should be perpendicular to a plane passing through the axes *cd* and *ef* of the legs.

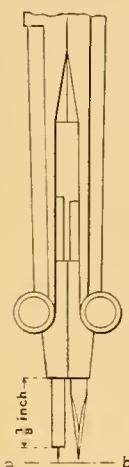


Fig. 13.

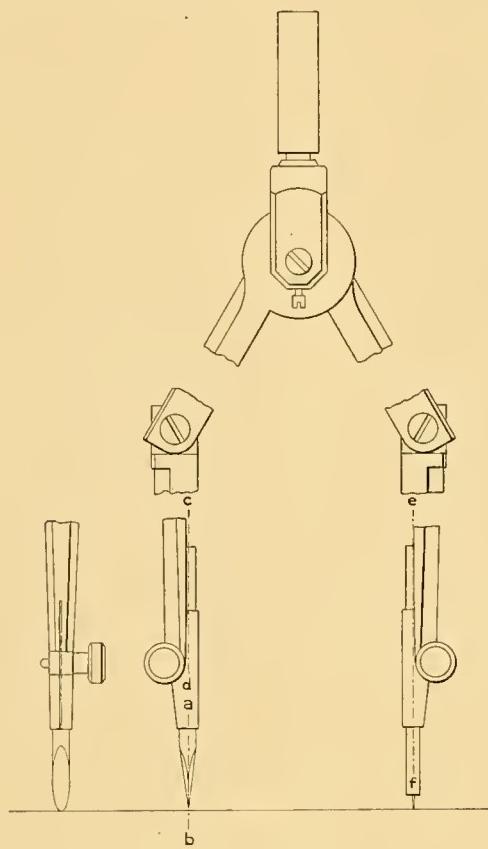


Fig. 14.

#### 24. The Plate, the Size of the Paper, the Border-line, Trimming.

(a) The subject matter of a drawing or plate is usually circumscribed by a ruled border-line, *EEEE*, Fig. 15. In laying out a drawing, the size and location of the subject matter may be determined with respect to a border-line of some given size, or, according to circumstances, the size and arrangement of the subject matter may determine the size of the border-line. When a drawing is completed and the border-line drawn, the width of the margin, *DDDD*, Fig. 15, of the plate should be laid off; lines *CCCC*, should then be ruled

through the points of measurement, and the plate trimmed on these lines. Therefore, before cutting off paper, *AAAA*, for a drawing, ascertain the required size by adding to the dimensions of the border-line twice the width of the margin, plus an allowance of extra paper, *BBBB*, for thumb tack holes,

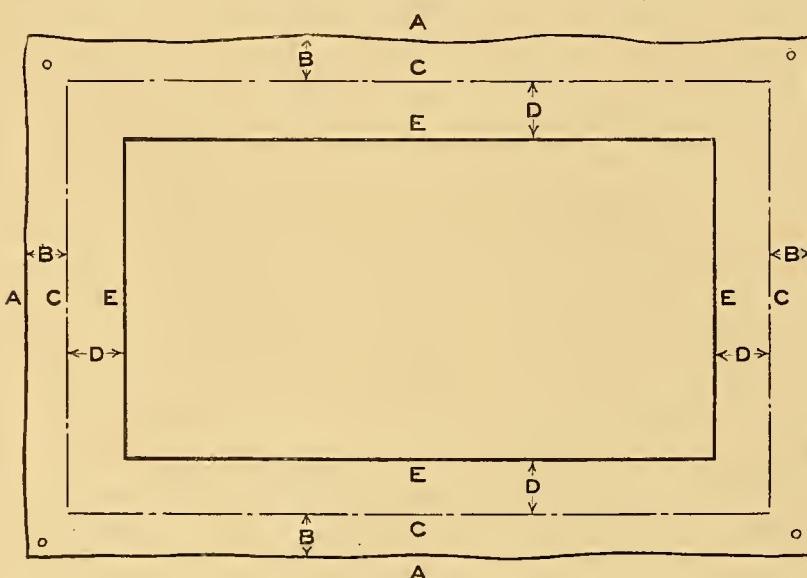


Fig. 15.

which should fall outside the trimmed edge.

(b) A very sharp knife should be used for trimming drawings. When trimmed on a board, the drawing should be placed in such a position that the knife will be drawn across the grain of the wood rather than in the direction of the grain. If this is

not done, the knife will tend to follow the grain and thus prevent a straight cut. In this respect the best cutting surface is thick, smooth cardboard laid on the drawing-board. Neither the regular drawing-board nor the T-square should be used in trimming drawings, but separate ones should be kept for this purpose. If, as a last resort, the drawing-board and the T-square are used, the cutting should be done on the back of the board, and along the lower edge of the T-square.

(c) In using the T-square, the bearing of its head against the drawing-board is maintained by placing the hand on the head below the blade (Fig. 7). When the blade of the T-square lies along the lower edge of the drawing-board, it becomes necessary to shift the hand above the blade in order to keep the head in position. This is both inconvenient, and a cause of inaccuracy, and should be avoided by placing the paper, when practicable, well above the lower edge of the drawing-board (Fig. 17). Never begin work on paper larger than the drawing-board; if the paper projects beyond the board, at once trim it so that all edges will lie at least  $\frac{1}{8}$  in. inside the edges of the board. Smooth out the paper flat on the drawing-board. Start the thumb-tacks at right angles to the board (*A*, Fig. 16), so that, when pressed in, their heads will bear evenly on the paper (*B*, Fig. 16). *Never use the T-square to drive in thumb-tacks.*

When not working on an unfinished drawing, keep it covered with a clean cloth, or paper. In making carefully executed plates, and elaborate drawings, all parts not in immediate use should be kept covered.

(d) *To lay out a border-line:* Take for example an 8 in. x 12 in. border-line with a 1 in. margin. Let *A A*, Fig. 17, represent the edges of the paper as cut for a drawing. With the aid of the T-square, place the edges of the paper approximately parallel to the edges of the drawing-board. Next, as it is likely that the edges of the paper are irregular and the sheet not square, draw, with T-square and triangle, horizontal and vertical lines, *BB*,  $\frac{1}{2}$  in. or less from the edge of the paper, as an allowance for trimming, and thumbtack holes. Perpendicular to lines *BB* lay off 1 in., the given width of the margin. Draw lines *CC* of indefinite lengths and lay off the width and the height of the

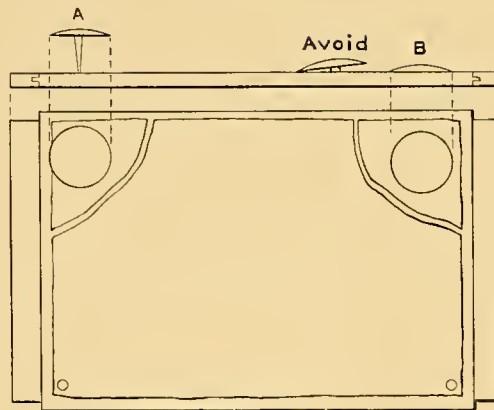


Fig. 16.

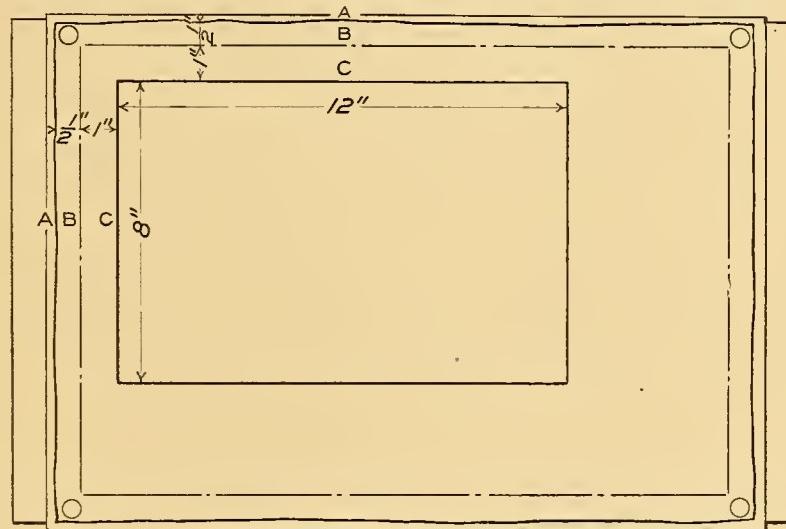


Fig. 17.

border-line. Complete the border with T-square and triangle. When a strictly accurate border is necessary, it should be laid out by geometrical construction.

(e) *Second Method.* It is sometimes convenient in laying out a border to work from the center of the sheet, in which case proceed as follows: Find the center *C* of the sheet (Fig. 18). Through this point draw *AB* and *DE*,

with T-square and triangle, horizontal and vertical lines, *BB*,  $\frac{1}{2}$  in. or less from the edge of the paper, as an allowance for trimming, and thumbtack holes. Perpendicular to lines *BB* lay off 1 in., the given width of the margin. Draw lines *CC* of indefinite lengths and lay off the width and the height of the

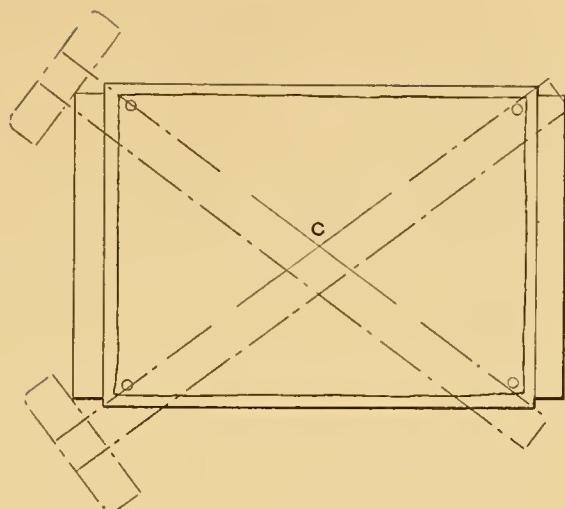


Fig. 18.

**25. Drawing Scales.** If the measurements of a drawing are the same as those of the object represented, the drawing is said to be "full size," and the scale commonly used is one of inches and sixteenths of an inch. Drawings are said to be drawn to a scale when they are made, for convenience or from necessity, smaller or larger than the areas or objects represented. For example, respecting areas, we may have a map of the United States drawn to a scale of 1 inch = 400 miles; also, surveyor's plans to scales of 50 ft. to the inch, 80 ft. to the inch, and so forth. Drawings of mechanical objects are made half size, quarter size or 3 ins. to the foot (written 3 ins. = 1 ft.), eighth size or  $1\frac{1}{2}$  ins. to the foot ( $1\frac{1}{2}$  ins. = 1 ft.) etc. Of the various drawing scales manufactured we shall speak of but two, the Architect's, divided as stated in the list of materials (Art. 1), and the Engineer's, having divisions of 10, 20, 30, 40, 50 and 60 feet to the inch.

(a) *To read the Engineer's Scale:* Take for example, the face of a 12 in. scale (Fig. 20), where each inch is divided into 50 parts, indicated by the "50"

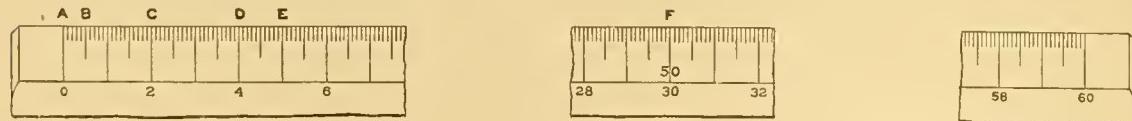


Fig. 20.

placed at the middle of the scale (see F). Each of these divisions represents 1 ft., and the scale is said to be one of 50 ft. to an inch. It will be seen that

Fig. 19, clear across the paper. On  $AB$  lay off  $CF$  and  $CG$  respectively equal to half the width of the required border-line. On  $DE$  lay off  $CH$  and  $CK$  respectively equal to one-half the height of the ruled border-line. Draw horizontal lines through points  $H$  and  $K$ , and through  $F$  and  $G$  draw vertical lines. An objection to this method is the erasure of the construction lines, which injures the paper for laying flat washes and other brush-work.

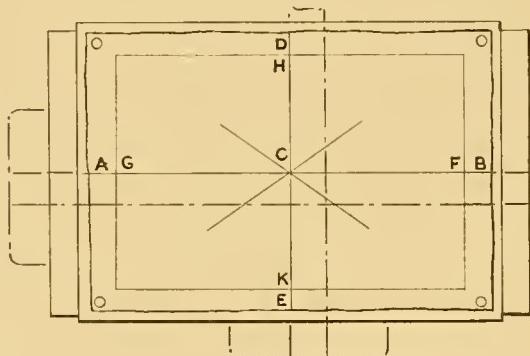


Fig. 19.

groups of five divisions, as  $AB$  (Fig. 20), and of ten divisions, as  $DE$ , are denoted by the greater length of the graduations, and that each group of twenty divisions is indicated by a figure stamped on the scale, as the "2" opposite  $C$ , which is read 20 ft. It will also be noted that inches are not distinguished by number; if required, these must be found by means of the group divisions and numbers. Thus for example, reading from the left-hand end of the scale, 1 in. is obtained by taking graduation  $E$  (Fig. 20), midway between the 4 ( $= \frac{4}{5}$  of an inch), and the 6 ( $= \frac{6}{5}$  of an inch). It will be seen, in the actual scale, that even inches fall on the numbered graduations, as the 6 ins. on the 30, while odd inches fall midway between them; as the 9 ins. midway between the 44 and the 46.

(b) *To read the Architect's Scale:* One face of the triangular Architect's Scale is divided to read inches, and sixteenths of an inch. On each of the

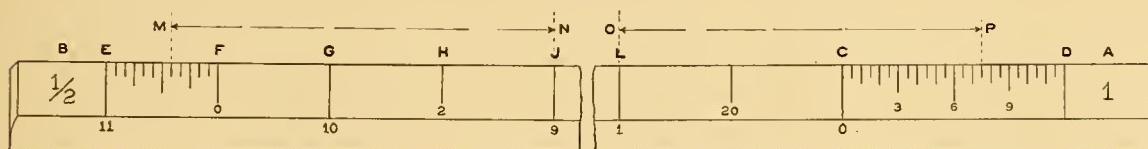


Fig. 21.

other faces are two scales combined into one. Take for example, the face of a 12 in. scale (Fig. 21), divided for scales of  $\frac{1}{2}$  in. = 1 ft., and 1 in. = 1 ft. It will be seen that each scale is denoted by a numeral, or a fraction, stamped at the end of the scale, as the " $\frac{1}{2}$ " in space  $B$ , and the "1" in space  $A$  (Fig. 21). Consider first the scale of 1 in. = 1 ft. The space  $CD$  ( $= 1$  in.) is divided proportionally to a foot rule, except that the lesser divisions of the foot rule are omitted in the scale, where the smallest divisions represent half inches. To use the scale, read both ways from the zero, opposite  $C$ ; inches to the right, feet to the left. Each whole foot is distinguished by a numeral (as the "1" opposite  $L$ ), which for this scale is stamped on the concave surface. For the scale of  $\frac{1}{2}$  in. = 1 ft., the space  $EF$  ( $= \frac{1}{2}$  in.) is divided, only here the smallest divisions represent inches. To use this scale, read both ways from the zero opposite  $F$ ; inches to the left, feet to the right. Each whole foot is marked by a line, while each second foot is distinguished by a numeral (as the "2" opposite  $H$ ).

To use the scale, apply accurately to the line to be measured, pressing it firmly upon the paper to minimize chance of error. To illustrate the reading of measurements, let it be supposed that the scale is applied carefully to lines  $MN$  and  $OP$ , Fig. 21. In the former the 3 ft. division is placed at point  $N$  and the reading is 3 ft. - 5 in. In the latter, the 1 ft. division is placed at point  $O$  and the reading is 1 ft. -  $7\frac{1}{2}$  in.

*The scale should never be used as a ruler.*

**26. Manipulation of T-Square and Triangles.** (a) Horizontal lines are usually ruled with the aid of the T-Square. Holding the T-Square as shown in Fig. 7,

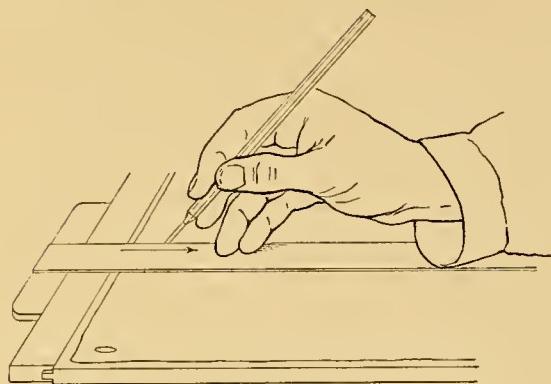


Fig. 22.

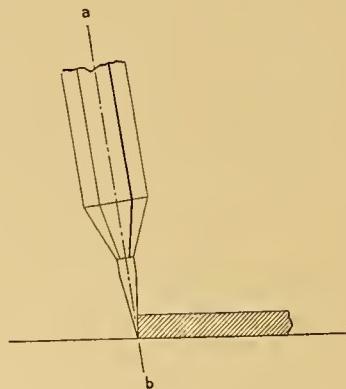


Fig. 23.

press its head firmly against the left-hand cleat of the drawing-board, and the blade flat against the paper. Incline the pencil to the right (Fig. 22), and slightly away from the T-Square blade (Fig. 23), so that the face of the lead will bear against the blade, and the point of the lead will lie in the line of contact of the edge of the blade and the paper. Let the fingers rest on the T-Square blade (Fig. 22); press the pencil firmly but lightly on the paper, carry it steadily from left to right, keeping the pressure uniform, and without changing the initial position of the pencil.

(b) Vertical lines are usually ruled with the aid of one of the triangles placed against the blade of the T-Square held as for horizontals. With the T-Square placed in position, the left hand holding its head firmly against the drawing-board, slide the hand from the head of the T-Square along the blade,—to keep it in position; place the triangle against the blade, (Fig. 24), with the

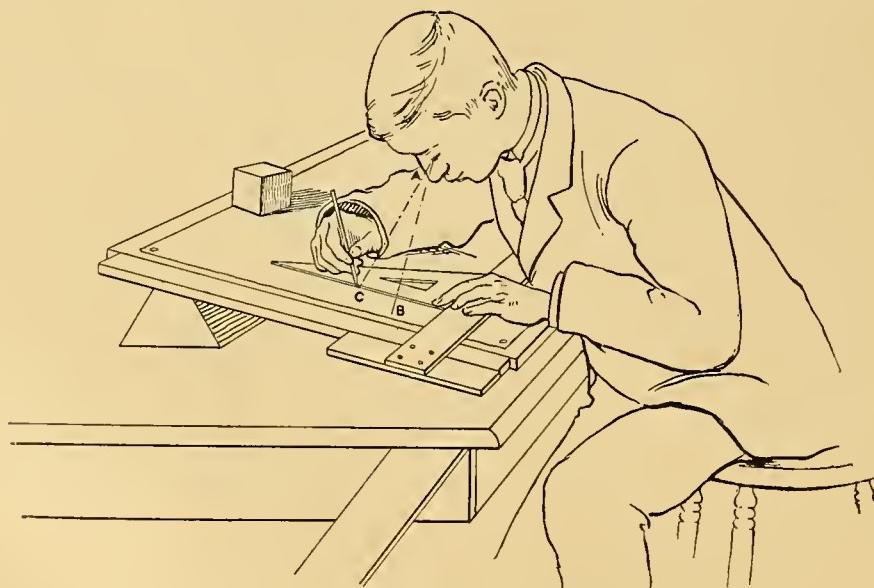


Fig. 24.

right hand, and hold the triangle in position with two fingers of the left hand (Fig. 24), thus freeing the right hand to manage the pencil. In ruling, the line of sight,  $AC$ , Fig. 24, should incline inward and forward from the perpendicular  $AB$  to the paper, in order that the ruling-point may be kept accurately in the line of contact of the edge of the triangle and the paper. Move the pencil *away* from the T-square blade rather than towards it. Care should be taken, on beginning a drawing, to place the work so that direct light will fall on the working edges of the T-square blade and the triangle. For accurate results, all vertical lines through-

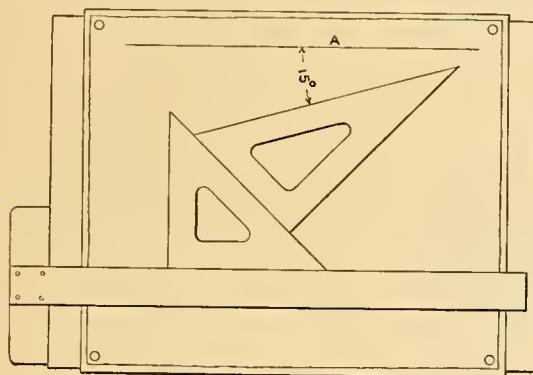


Fig. 25.

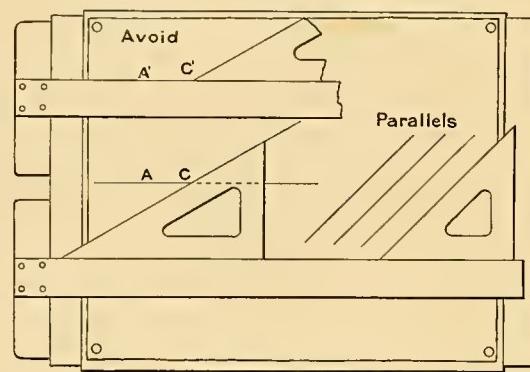


Fig. 26.

out the drawing should be drawn with the same edge of the same triangle, and care should be taken that this triangle is not turned over or reversed.

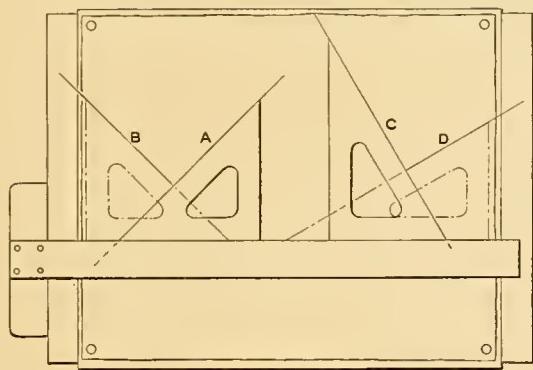


Fig. 27.

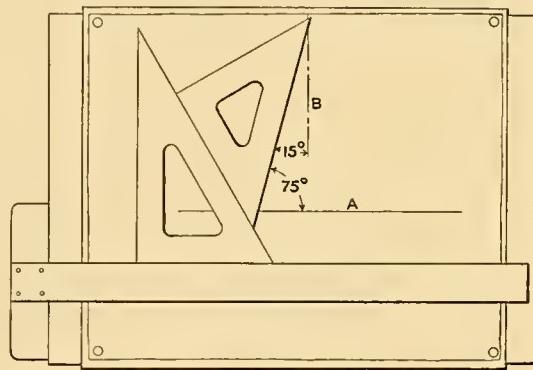


Fig. 28.

(c) Lines making the angles of  $15^\circ$ ,  $30^\circ$ ,  $45^\circ$ ,  $60^\circ$ , or  $75^\circ$  with the horizontal are ordinarily drawn as shown in Figs. 25–28.

In drawing a line through a given point, as  $C$ , in line  $AC$  (Fig. 26), do not fit the T-square to the line as at  $A'C'$  (Fig. 26), and then attempt to place the corner of the triangle at the point, as at  $C'$ , but keep the T-square blade away from the line, as at  $AC$ , and pass the edge of the triangle through the point.

(d) For lines parallel or perpendicular to an oblique line, or making the angles of  $15^\circ$ ,  $30^\circ$ ,  $45^\circ$ ,  $60^\circ$ , or  $75^\circ$  with it, we ordinarily use only the triangles.

To draw a line parallel to a given line: Let it be required to draw through point  $C$  (Fig. 29) a line parallel to  $AB$ . Fit accurately to the given line an edge

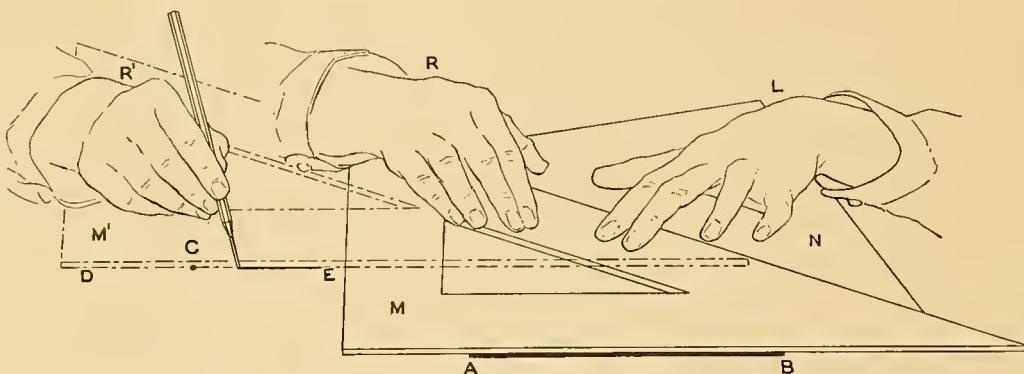


Fig. 29.

of either triangle, as  $M$ , and place against it another triangle, as  $N$ . Hold  $N$  firmly in place with the left hand,  $L$ , and slide the triangle  $M$  along  $N$  to position  $M'$ , with its edge passing through the given point  $C$ . Keep  $M'$  and  $N$  firmly in position with the left hand, to free the right hand for drawing the required line, as from  $E$  through  $C$ .

Positions of the triangles for drawing a perpendicular to an oblique line, or for making with it any of the angles stated above, are shown in Fig. 30, which is intended for general reference. The solid black represents a fixed triangle; and the dash and dot, a movable triangle set upon the given line. The full line—the triangle which guides the pencil—shows either the new position of the movable triangle, or the position of a triangle substituted for it ( $J$ ,  $K$ ,  $L$  and  $M$ ). The method  $C$ , Fig. 30, which uses two movable triangles, is occasionally more convenient, although less direct than the other methods giving the same results.

(e) *The protractor.* This instrument, used for laying off angles, is a semi-circular disc, or arc—made of metal, horn, cardboard, etc.—divided into degrees, half, and quarter degrees. Metal protractors with a vernier attachment read to one minute.

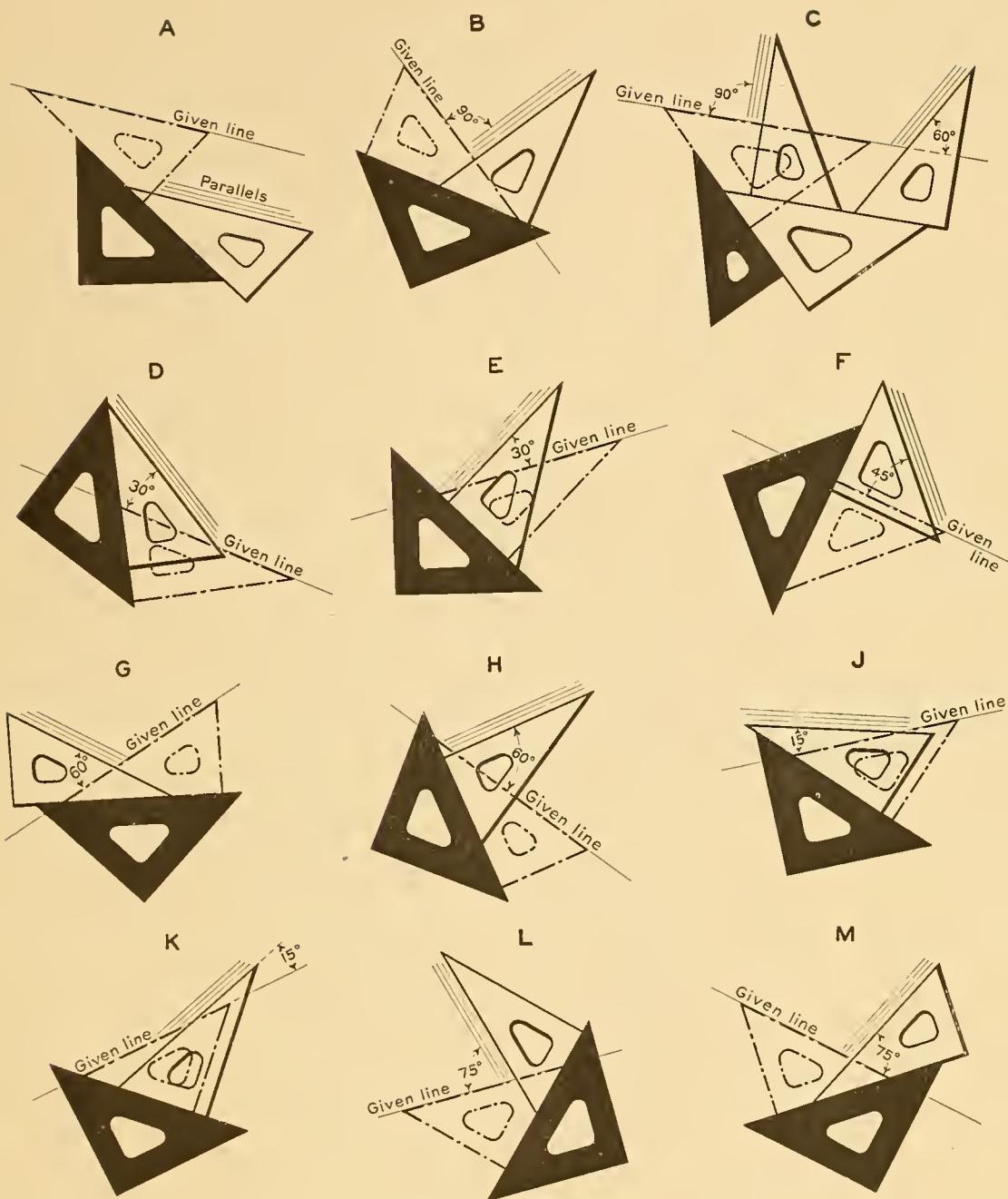


Fig. 30.

**27. Handling the Compass.** Large circles and circular arcs are drawn, according to length of radius, with the compass, the compass with the extension bar, or the beam-compass. For small circles of, say,  $\frac{3}{4}$ -inch radius or less, the bow-compass is used. In drawing circles and circular arcs, the shoulder tip of the

needle-point (Plate 1) should be used, and the lead of the compass should be sharpened and adjusted in the socket according to *d*, Art. 23.

(*a*) *To describe a circle.* First set the compass approximately to the re-

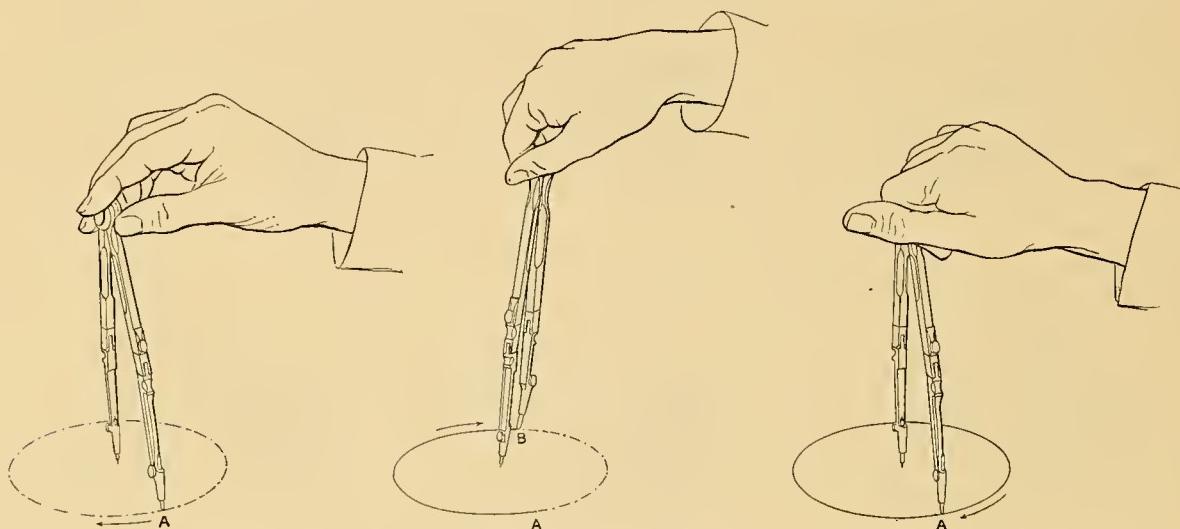


Fig. 31.

Fig. 32.

Fig. 33.

quired radius, with the *legs bent* so that each will be perpendicular to the paper (Fig. 14). Then set the compass to the exact radius. Now hold the head of the compass with the tips of the thumb and the index and middle fingers (Fig.

31), and place the lead at *A*, which represents a point as near as practicable to the foot of a perpendicular let fall from the inner side of the wrist to the paper. The needle-point should merely rest on the paper; do not puncture the paper, but give the instrument only enough pressure to keep the needle-point from slipping, and to obtain the friction necessary to draw a very narrow, sharp-cut, and light but distinct line. Incline the head of the compass slightly forward in the direction of its motion,—as indicated by

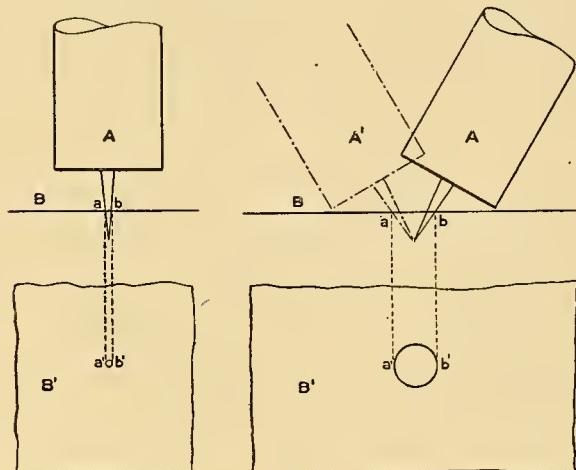


Fig. 34.

Fig. 35.

the arrows, Figs. 31–33,—and describe the circle with one continuous sweep of the lead. The compass should be guided by a combined finger, wrist, and arm movement, the head of the instrument meanwhile rolling between the thumb and forefinger (Figs. 31–33).

The need of bending the needle-point leg and of inclining the compass but slightly to the paper is shown in Figs. 34 and 35, where *A* represents an enlarged needle-point, *B* an edge of the paper, and *B'* its surface. When the needle-point is perpendicular to the paper (Fig. 34), if the latter is accidentally punctured, the hole or center thus made will have a diameter  $a'b'$ , equal only to the diameter  $ab$  of the point. If, however, the needle-point is inclined (Fig. 35), the swinging of the compass is very likely to cause the needle-point to ream out the puncture to an extent ( $ab$ ,  $a'b'$ ) which prohibits the further use of the center for accurate work. Do not carry the lead back and forth; once drawn, let a line stand,—improvement should come from practice, and not from going over or patching the lines. *Never use the instrument as shown in Fig. 36.*

(b) *The lengthening bar.* When the lengthening bar (Fig. 37) is used, the compass is likely to spring under pressure; hence it must be handled lightly.

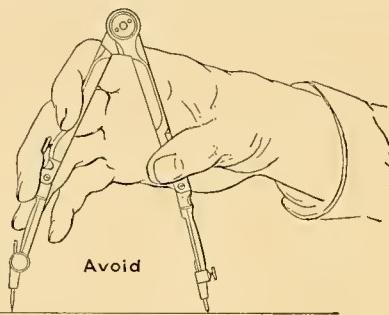


Fig. 36.

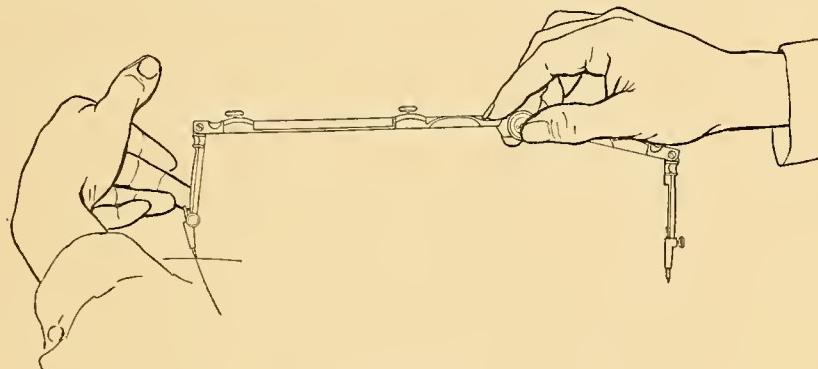


Fig. 37.

Bend the legs to bring them perpendicular to the paper; incline the instrument slightly, in the direction of its motion, and at the beginning and end of the line guide the describing leg with a finger of the left hand.

(c) *The beam-compass.* This instrument (Plate 3) is practically a compass with a separated head (*A* and *B*, Plate 3) which slides on a wooden bar. Slight corrections of distance between the legs of the compass may be made by means of the spring regulated by the nut *C*.

**28. The Ruling of Curves.** (a) Elliptical and all other curves not circular require the use of a curved ruler, one style of which is called the irregular or

French curve (Plate 2). When the points in a curve have been located, they should first be connected by a free-hand line sketched very lightly with a 3H or 4H pencil having a sharp point. In sketching this line, care should be taken to pass it accurately through each of the points located, and at the same time to obtain a curve as graceful as possible; furthermore, the freehand line should be drawn *directly*, since excessive correction tends to obscure, or wholly to obliterate, the located points. The free-hand curve having been sketched, the final line, usually ruled directly in ink, should be drawn with the French curve as follows: Let  $BCD$  (Fig. 38) be a series of points connected free-hand as just described.

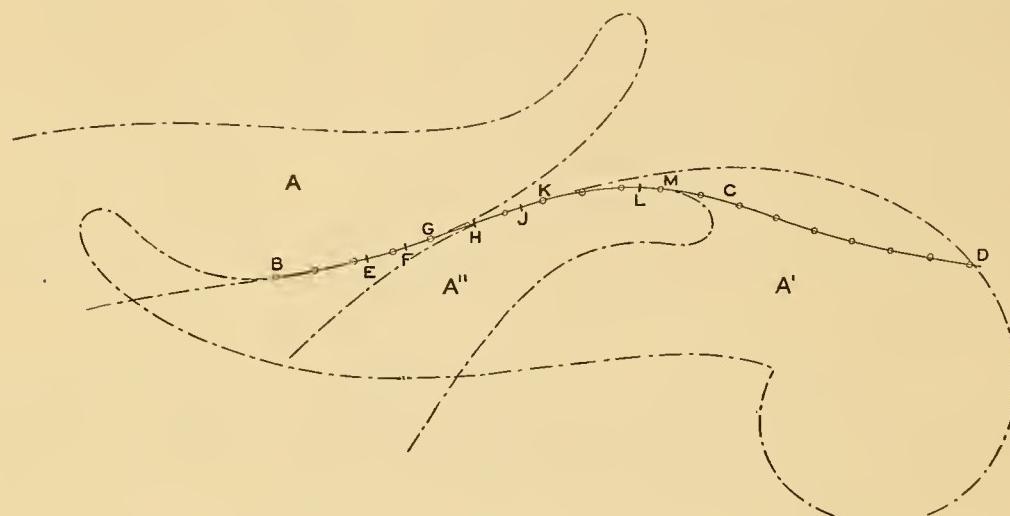


Fig. 38.

The next step will be to find by trial, from among the stock of French curves, those having portions which will coincide with or accurately fit the sketched line, taken in consecutive sections, each of which should be as long as practicable. In order to insure smoothness of curvature in the line as a whole, in ruling each succeeding section the French curve must be fitted back some distance on the preceding (inked) section. Likewise and for the same reason, in ruling each section, the line should stop a little short of the full length of the section. These requirements are illustrated in Fig. 38. Curve  $A$  fits section  $BG$  of the sketched curve  $BCD$ , but the ink line is carried only from  $B$  to  $F$ . Curve  $A'$  fits section  $GK$ , and also fits back on section  $BG$  to include portion  $EF$  already inked. The ink line is carried from  $F$  to  $J$ ; that is, distance  $JK$  short of the full length of section  $GK$ . Curve  $A''$  fits back on section  $GK$  to  $H$ , which includes portion  $HJ$  already ruled, and forward to point  $M$ . The ink line is carried from  $J$  to  $L$ .

*In ruling curves, the pen should be held perpendicular to the paper (Fig. 39), so that, when carried around sharply curving portions of the French curve, it may turn easily on its point.*

(b) *A template.* This is a substitute—made by the draftsman—for the French curve, and used either as a time-saving device, or when the French curve cannot be fitted to the located points. It is made of thin sheet metal, wood, rubber, or celluloid. If thin wood is used, the required curve may be drawn directly on it. In the case of rubber or celluloid the curve should be traced and then transferred to the rubber by pricking through the points (*c*, Art. 29). The template should be roughed out with a pen-knife or hand fret-saw, then formed with a coarse file, and finished with a fine file.

29. **The Pricker ; Precision in Noting Line Intersections and Scale Measurement ; Duplicate Drawings.** The pricker is used to define line intersections, to lay off measurements from the scale, and in duplicating drawings. A fine needle should be used, and immediately replaced when the point becomes at all blunted. Hold the pricker perpendicular to the paper (Fig. 40).

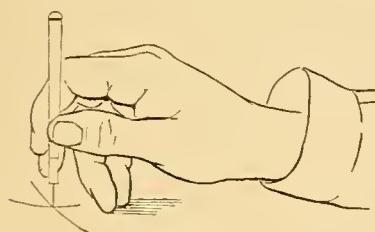


Fig. 40.

In the case of intersections and scale measurements, do not drive the point of the needle through the paper, but make an indentation which is barely visible. Immediately, when an isolated point or one denoting measurement is noted, the point should be enclosed in a small free-hand circle.

(a) *Line intersections.* In noting line intersections, the beginner is very likely to be careless. If

strictly accurate results are specified, it is not sufficient merely to glance at the intersections; they must be closely scrutinized and noted with the greatest precision. To this end we may conceive every line, however narrow, to have an imaginary center-line. For instance, in Figs. 41 and 42 the black areas (*B*) represent the given lines (*A*) supposed to be magnified; the white lines on the black areas represent the imaginary center-lines of



Fig. 39.

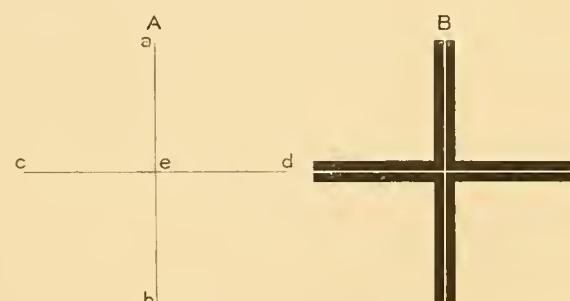


Fig. 41.

the given lines. For strict accuracy, we must regard intersections *e* (*A*, Figs. 41, 42) as intersections of the imaginary center-lines of *ab* and *cd*, and corresponding to the intersections of the white lines (*B*). To illustrate further, let us consider a point of tangency, as that of lines *ab* and *cd*, Fig. 43. Having first determined the point *g* by locating geometrically the line *ef*, in pricking the point with

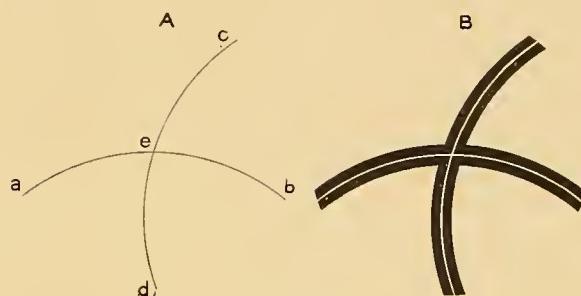


Fig. 42.

the needle we must see in imagination the center-lines of *ab*, *cd*, and *ef*, as suggested by the white lines on the black ground (*B*).

(b) Equally important in precise drawing is close observation in laying off scale measurement. Here,

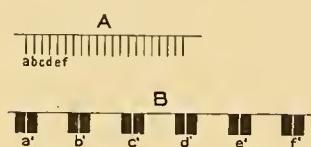


Fig. 44.

also, we should note the imaginary center-line, in this case that of each graduation required to be indicated (see *a'*, *b'*,—*f'*, *B*, Fig. 44, which represents the graduations of actual scale *A* enlarged).

(c) Diagrams, maps, and other drawings are sometimes duplicated as follows: Place the original over a fresh sheet of paper. Prick through its essential points, and connect the new points in the usual ways.

The pricker must be held perpendicular to the paper. In order that points in the duplicate may be readily found, as well as to guard against connecting wrong ones, each point should be circled freehand, and lettered or numbered.

**30. Spacing with the Hair-spring Dividers.** The hair-spring dividers and the bow-spacers (Plate I) are used to transfer distances, and to space or divide lines into equal parts.

(a) *The general process.* Before commencing to space, ascertain the range (*BC*, Fig. 45) of the hair-spring leg by turning the screw *E*. Set the point of the leg at

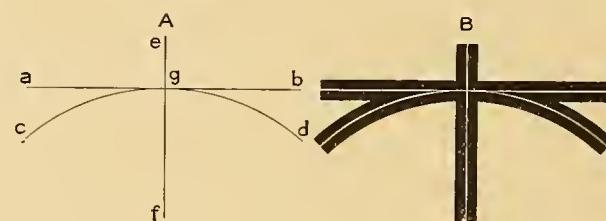


Fig. 43.

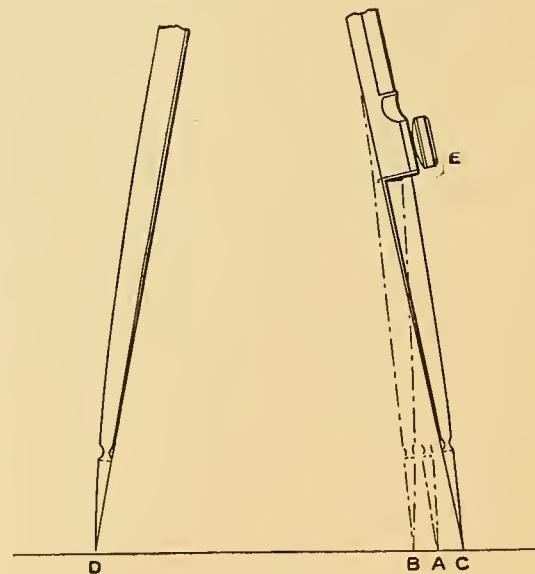


Fig. 45.

*A* midway between *B* and *C*. Let it now be required, for example, to divide line *D'B'* (Fig. 46) into 13 equal parts. Take between the points of the dividers—

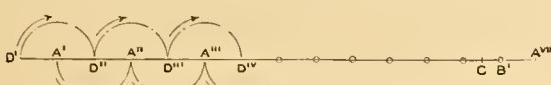


Fig. 46.

moving the legs by means of the head-joint—a distance as nearly equal to  $\frac{1}{13}$  *D'B'* as can be judged by eye. Starting with one leg of the dividers placed at *D'*, step along the given line until

the 13 spaces are laid off. If, in laying off the last, or 13th, space, the leg of the dividers extends beyond the given line, as distance *B'A''''*, the assumed distance taken in the dividers must be decreased by  $\frac{1}{13}$  of the excess, *B'A''''*, determined by judgment. If, however, in laying off the 13th space, the leg of the dividers does not reach the end of the line, as at *C*, it is evident that the distance in the dividers must be increased by  $\frac{1}{13}$  of the deficiency *CB'*.

In correcting a distance in the dividers, if the error is a considerable one, the leg of the instrument should be moved by means of the head-joint. For a slight correction use the hair-spring, which, as already stated, should be set before beginning to space, so that the leg may be moved in either direction according to necessity.

(b) *Refinements in spacing.* To divide a line accurately into any considerable number of parts requires close observation, careful manipulation of the dividers, and strict attention to the following details. As to the instrument, its points should be very sharp, of exactly the same length, and, when closed, should come together accurately. If the points are blunted, or of unequal length, the defect should be remedied on the oil-stone. Until a close approximation to the required spacing unit is obtained, the dividers should be stepped parallel to and a little to one side of the given line in order not to mar it. In stepping the dividers, care should be taken not to spring them, and thus change the distance between the points of the instrument,—a result which will follow if the points are thrust into the paper. When a close approximation to the required spacing unit has been obtained, the trial spacing should be transferred to the given line; but the paper must not be punctured or perceptibly indented, since the points of the dividers are very likely to slip back into the puncture, or indentation, and thus to frustrate all efforts for a satisfactory result. At this stage of the spacing, it is not sufficient that the points of the dividers fall somewhere near the given line, or even somewhere on this line; but they must be placed on the imaginary center-line of the given line, as suggested by the white line on the black ground (*B*, Fig. 47)—using a reading-glass (Plate 2) if necessary.

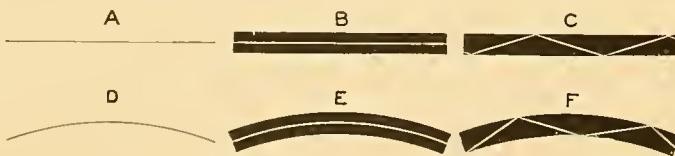


Fig. 47.

To illustrate, in the enlargements *C* and *F* (Fig. 47), the points of the dividers are supposed to fall on opposite edges of the given lines (*A* and *D*). It will be seen that the distances between the points of the dividers—represented by the white lines in *C* and *F*, instead of being laid off in one direction, as when they fall continuously on the imaginary center-lines (*B* and *E*), are laid off in a zigzag line. Now, if the points of the dividers happen to fall several times on the inner edge of the given line, then several times on the outer edge, next on the imaginary center-line, and so forth, there may occur an appreciable accumulated error. To minimize chance of error in this particular, let the advancing leg swing in alternate directions, as indicated by the lettering and arrows (Figs. 46 and 48). In indicating a final spacing, the paper should be merely indented, and this not directly, but by going over the given line several times, each time with just enough pressure to indent the paper visibly *after* the several repetitions.

(c) *Proportional dividers.* This instrument (Plate 3) is occasionally very convenient in making reduced or enlarged copies of drawings, photographs, or prints. A required ratio, as between distances *ab* and *cd* (Plate 3), is obtained by means of the sliding joint *A'*.

**31. Inking; the Ruling-pen.** A drawing may be inked for each or any of these purposes: greater distinctness, finish, or durability. Inking should always be preceded by accurate pencil construction, except in the cases of small tangent arcs, conventional screw-threads, and parallel lining (cross-hatching) used to denote a section of an object, when it should be done without preliminary penciling. India ink should be used; writing inks are wholly unsuitable. For best results it is necessary to use the stick ink ground in water. The ready prepared drawing-inks, while convenient for rush work in office practice, are not here recommended for finished drawing, since they are likely to flow less satisfactorily than the freshly ground ink, to be not strictly black, and to attack the paper more quickly.

(a) *To prepare India ink.* Fill the ink-slab (Plate 2) with water sufficient to overflow the ink-well. Hold the stick of ink vertical, and with a moderate pressure give it a rotary motion around the edge of the ink-well. The grinding should be continued until the ink is *absolutely black*, but not *thick*. This requires ordinarily from five to ten minutes, according to the hardness of the ink and the amount of water used. As the grinding proceeds, the condition of the ink should be ascertained by lines on drawing-paper made with the ruling-pen; but do not try to judge the blackness of the ink until the line is dry. After grinding, the stick of ink should be wiped dry to prevent cracking. *Keep the ink covered.*

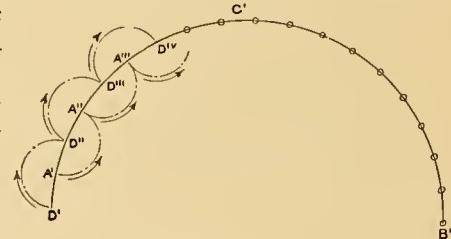
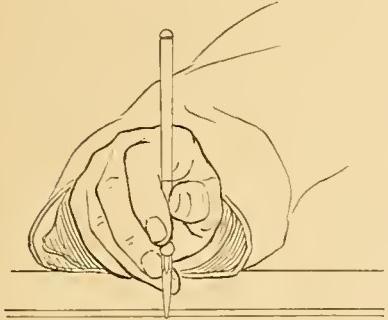


Fig. 48.

(b) *Ruling.* Open the blades of the pen  $\frac{1}{16}$ " or less, let the ends rest in the ink a moment, close the blades, and carefully wipe off all superfluous ink with a rag or the chamois leather. If preferred, the common writing-pen, or a quill may be dipped in the ink and then passed between the blades of the pen. Always, before inking is begun, the pen should be tried — on paper of the kind used in the drawing — to see that the ink flows freely and that the line is of the right width. Avoid the habit of touching the pen to the lips, to cause the ink to flow. If one or two trials on the edge of the paper, on the finger, or on the drawing-board — when the pen should follow the grain of the wood — will not suffice, either the ink is too thick or the pen needs to be cleaned.

It is best to hold the pen perpendicular to the paper (Fig. 49), or very nearly so, with the set-screw turned outward. Thus held, the pen will not cover the point to which a line is required to be drawn, as is the case when the pen is inclined. Carry the pen from left to right steadily, rather slowly, and without any rotation about the axis of its handle. To satisfy this last condition, the position of the hand relative to the ruler must not change; this is effected by an arm movement from shoulder and elbow, without wrist motion. In the case of long lines a slight movement of the wrist appears to be necessary, but this should not be allowed



to change the position of the hand relatively to the blade of the T-square or the straight-edge. Except in the case of curved shade lines, ruled lines should be of uniform width throughout, and wholly free from ragged edges. If the handle of the pen is inclined outward — with the object of bringing the point into the line of contact of the ruler and the paper — the ruler, especially if made of rubber, is likely to attract the ink and thus to blot the paper. Blotting-paper should always be at hand in case of accident. *Do not set the ink-slab on the drawing-board, or hold the pen over the drawing while filling.*

(c) *The care of the ruling-pen.* The blades of a good drawing-pen are highly tempered and therefore brittle; care should be taken not to break their points by screwing the blades too tightly together, or, when filling the pen, by striking the points against the ink-well. If a pen works badly, the blades should be slightly separated, and examined with a magnifying glass to see whether the points are broken, dull, or of unequal length. If the points are dull, this will be indicated by a light spot — due to the light reflected by the blunted points — seen when the pen is viewed endwise. Every student should learn to sharpen his pen, since inability to do this may prove to be a serious handicap if he chances in the future to be located at a point remote from instrument repair shops.

(d) *To sharpen the ruling-pen.* Use a fine oil-stone, and plenty of oil. With the blades closed, hold the pen perpendicular to the face of the oil-stone, as indicated by views *A* and *D* (Fig. 50). While keeping the pen in a plane per-

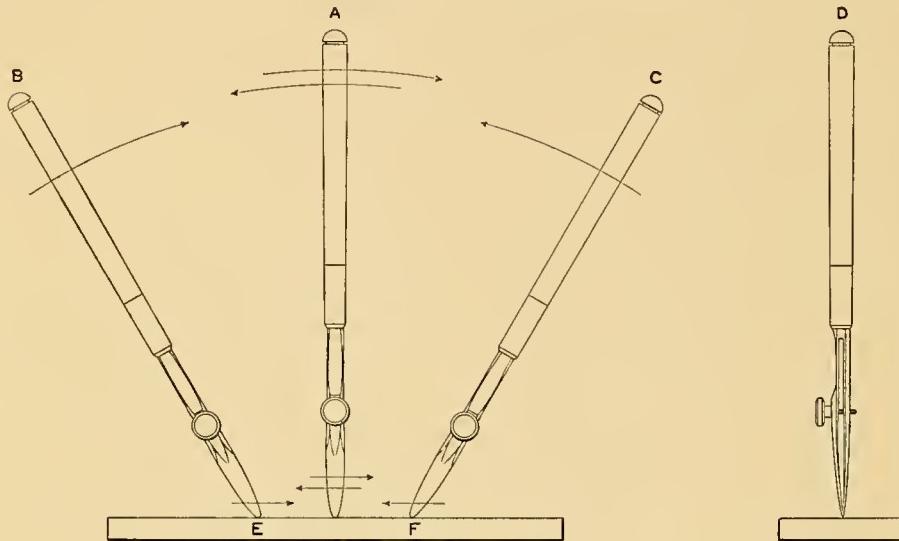


Fig. 50.

pendicular to the surface and parallel to the long edges of the oil-stone, carry the pen back and forth, and at the same time rock the pen as indicated by positions *B* and *C*, Fig. 50. This should bring the blades to an equal length and give them points which, for the view of the pen shown in *A*, Fig. 50, are elliptical in outline. Now grind separately the point of each blade as follows:

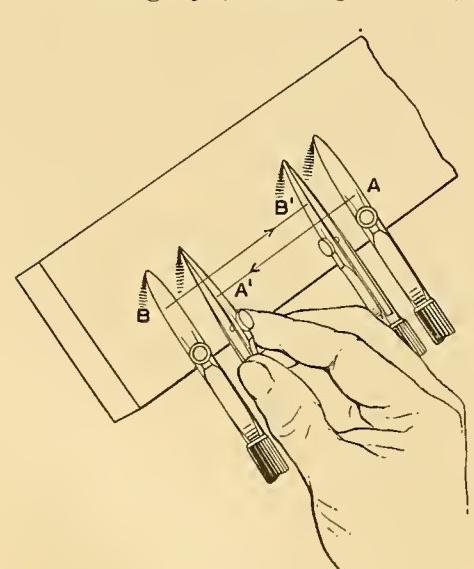


Fig. 51.

Hold the pen as shown at *A*, Fig. 51, making an angle of about  $10^\circ$  or  $12^\circ$  with the surface of the stone. Carry the pen back and forth as indicated by the arrows, and, while so doing, rotate it about the axis of its handle. In this rotation the right-hand edge of the blade, in passing from *A* to *A'*, gradually approaches the surface of the stone. At *A'* the pen is rotated to correspond to its initial position at *A* (see *B*), and in the stroke from *B* to *B'* the left-hand edge of the blade gradually approaches the stone. The pen is again rotated to its initial position at *A*, and the motions are continued. In a cross-section of the point thus made the curved portion of its outline should be approximately elliptical. As the work proceeds, the point should be examined from time to time with the reading-

glass (Plate 2), and the pen should be tested by lines carefully ruled on paper of the same kind as is used in the drawing. As a rule, care, patience, and considerable time are necessary in order to grind a pen properly.

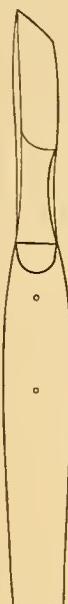
**32. Tracing.** For temporary drawings, for transfers, and in planning, tracing-paper is well-nigh indispensable. Tracings for blue prints and tracings required to stand handling, and ink erasure, should be made on tracing-cloth.

The dull surface of the tracing-cloth is suitable for penciling and inking. Washes of India ink and color may be used on the dull surface if applied sparingly ; but even then—since water destroys the sizing—the cloth will cockle. If color washes are used, inking should be done on the opposite or glazed side. A very good substitute for color washes, which is growing in favor, is hard colored crayon ; this may be simply rubbed on the dull surface, or, in addition, worked flat with a stump. The glazed surface of the cloth is adapted only for inking ; although for this work the dull surface appears to be generally preferred. If the cloth does not take the ink satisfactorily, it should be thoroughly cleansed by rubbing with soft paper, or sprinkled with powdered chalk (scraped from blackboard crayon), which should be lightly rubbed into the surface and then dusted off *thoroughly*. As tracing-cloth is very susceptible to moisture—which causes it to stretch—it should not be used when permanent accuracy of drawing is required.

**33. Erasure.** (a) *Pencil-lines.* Use a soft rubber which is clean and pliable. To erase within a small space, the rubber may be shaved to a point or to a wedge-shaped edge ; and a card may be used, if necessary, to protect adjacent lines. For large areas the sponge rubber is convenient and time-saving. When erasing near the edges, special care must be taken not to crumple the paper or the tracing-cloth ; hold it down firmly with the thumb and finger, and erase between them.

(b) *To remove ink-lines from drawing-paper.* In the correction or removal of ink-lines or of blots, and in the subsequent redrawing of lines after erasure, the work should be so nicely done that the result will in no wise mar the drawing,—a matter requiring care and considerable skill. In an erasure, every vestige of ink should be removed. Both the steel eraser and sand rubber (rubber ink-eraser) may be used to advantage, and the first step toward skilful erasure lies in keeping the

Fig. 52. steel eraser very sharp. The scalpel (Plate 2), if a new one, should be reground, and afterwards kept to a keen edge by frequent whetting on the oil-stone. The form shown in Fig. 52 is recommended. This edge, but slightly convex, is best adapted for erasing areas ; while the point, if kept sharp, is very satisfactory for minor erasures and cleaning up ragged lines.



Before beginning to erase a line, note with the finger whether sufficient ink is deposited on the paper to give the line appreciable relief. If so, the steel eraser should first be used — carried along the line, not crosswise — to remove as much of the ink as possible without scraping the paper; after which the sand-rubber should be applied. In using any kind of eraser, the principal thing is not to make grooves or ruts in the paper; hence the eraser should be carried over the paper for some distance on all sides of the area to be removed, so that the paper may be worn away uniformly. To the same end, in converting a full line into dashes, carry the steel eraser back and forth in the direction of the line, not crosswise. To prevent ink from spreading, when redrawing after erasure, the surface of the paper should be thoroughly but lightly polished with the burnisher (Plate 2). Excessive gloss, due to burnishing, may be removed, after the redrawing is finished, with the soft rubber.

Especially useful is the erasing shield — cut out of thin sheet rubber, celluloid, bristol-board, or paper —, and used in connection with the rubber eraser. Various

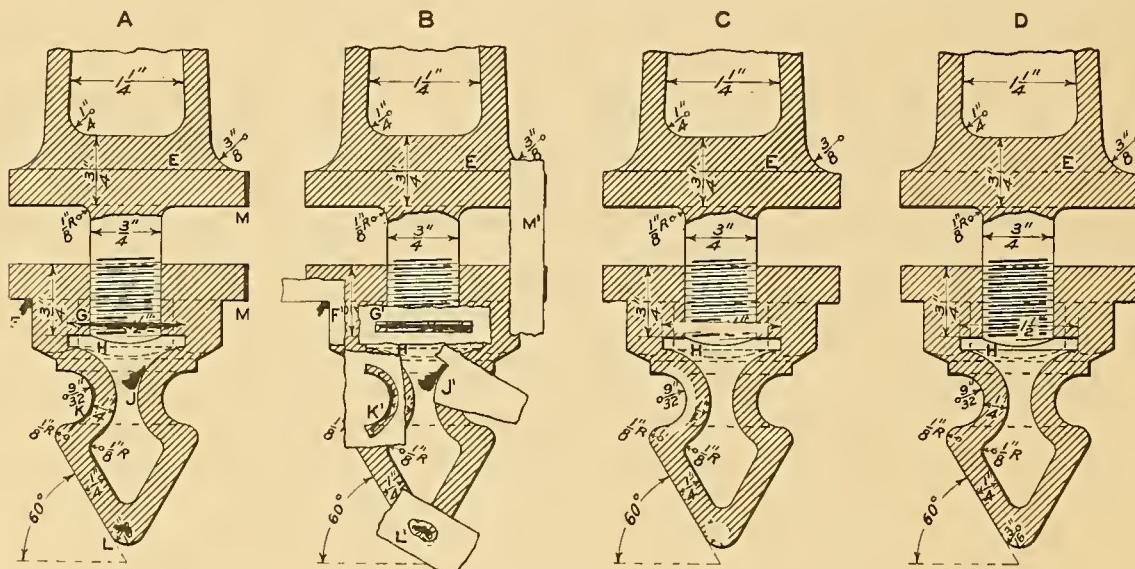


Fig. 53.

forms of this device are suggested in Fig. 53, which represents a section of the lower end of a locomotive hand-rail stud. Cut *A* shows a supposed series of mis-haps (*F*, *G*, *J*, *K*, *L*) to the drawing; *B* shows the various shields (*F'*, *G'*, *J'*, *K'*, *L'*) used in erasing the accidents; in *C* we have the drawing after making the erasures; and in *D* the restored lines. The shield *M'* (*B*) is used in reducing the excess width of the shade lines *M* (*A*). The full line lettered *E* (*A*, *B*, *C*) is mistake in inking, since, as the line in the drawing represents an invisible edge of

the object, it should be expressed by dashes (see *E*, cut *D*). The line lettered *H* (*A*, *B*, *C*) represents a visible edge of the object (see *H*, cut *D*), and should therefore be made a full line.

(c) *To remove ink-lines from tracing-cloth.* Slip a piece of cardboard, or the triangle, under the cloth for a backing, and erase with either a ruby or emerald rubber, after having first removed accumulations of ink with the steel-eraser, which must not come in contact with the cloth. Before redrawing, apply talc (sold by hardware dealers under the name "metal worker's crayon"), and then polish with the burnisher. Lines drawn on the glazed surface of the cloth can be much more easily removed with the soft rubber than lines drawn on the dull surface; but in neither case should the sand rubber be used, as it will quickly wear a hole through the cloth.

## CHAPTER II.

### RENDERING; WORKING METHODS; LETTERING AND DIMENSIONING; STUDY PLATES.

34. **Rendering.** This term signifies results wholly dependent upon the material used and the manner in which it is applied to the drawing-surface. Thus, for example, we have line-drawings in pencil, and in ink; shaded drawings, rendered with pencil, pen and ink, or brush; finished drawings, sketches, and suggestions. Various line-renderings or conventions are shown in Fig. 54. Greater

For problems	Full line . . . .	A
	Dash line . . . .	B
	Dash and dot line . . . .	C
For working drawings	Visible lines . . . .	D
	Shade lines . . . .	E
For working drawings	Invisible lines . . . .	F
	Center-lines . . . .	G
	Extension lines . . . .	H
	Dimension lines . . . .	J

Fig. 54.

distinctions of line may be obtained by using colored inks; and much time may be saved by substituting for dashes, when practicable, full line in color.

35. **Working-methods.** We use this term to indicate methods which have sprung from the necessities or customs of engineering practice, as well as to distinguish processes immediately effective or practical from those which are educational on general lines.

For convenience, merely, we separate the process of drawing into two general stages, a *first*, or *constructive*, and a *second*, or *final*, stage. Furthermore, we may assign to each general stage any number of special or local stages. Thus,

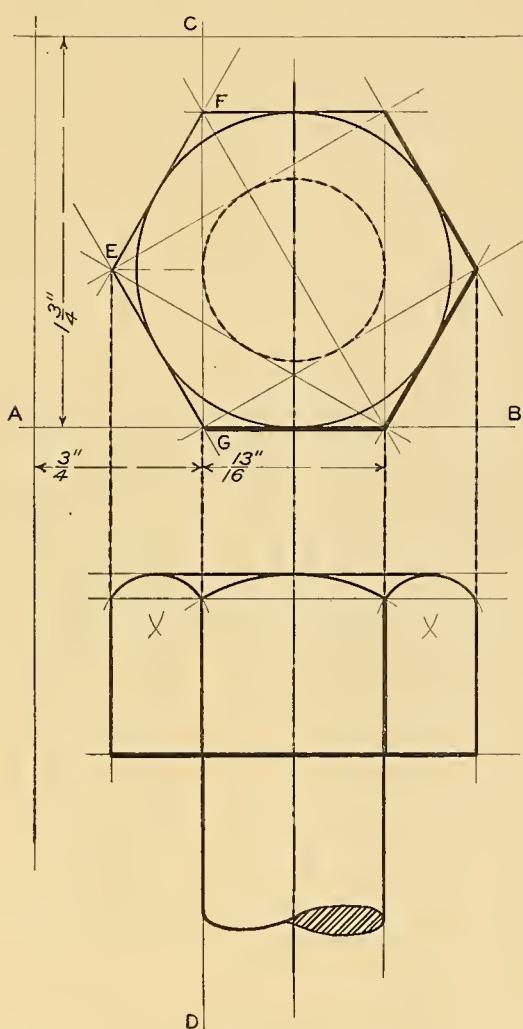


Fig. 55.

example, the first stage of a pencil or of an inked drawing is represented by the laying out of the drawing and all other pencil work which precedes the finished lining-in of the pencil-drawing, or the inking, lettering, etc., of the inked drawing.

(a) *Penciling; working-methods.* The accuracy with which a drawing is penciled should invariably represent the required accuracy of the final drawing; that is, essentials must never be slighted in pencil and left for correction in the inking. All pencil-lines (represented by the narrow lines, Fig. 55) should be made with a 6H pencil and *full*, light, and very narrow. *Line conventions* (see the wide lines, Fig. 55), both in pencil and in ink, belong to the second stage of the drawing. In lining in finished pencil drawings, use a rather soft pencil (F to 3H) and emphasize the lines strongly. In the case of dash, and dash-and-dot line, do not erase between the dashes, as lightly drawn lines of the first stage become inconspicuous when the final lines are properly emphasized. Lines upon which measurements are to be laid off — as was the case in drawing AB, Fig. 55 —, and lines required to be intersected

by subsequent ones, as  $EG$ ,  $EF$ , must be drawn long enough to insure the laying off of the measurement, or the intersection, without patching out the line. An

objection to dash-lines, in the first stage of the drawing, is suggested by Fig. 56, in which *A*, *B*, and *C*, required intersections, are merely open spaces between the dashes.

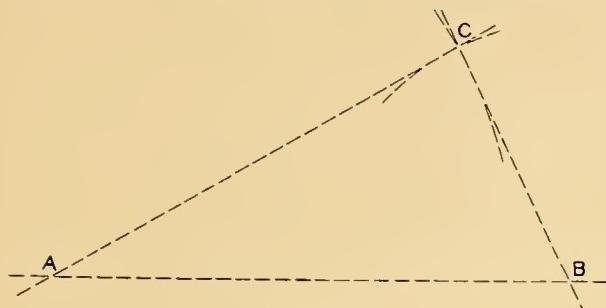


Fig. 56.

*D*, and *E*. Beginning at the upper left-hand corner of the drawing, and, to avoid wet ink, working downward and from left to right, we first ink (*B*, Fig. 57) all circles and arcs of the same radius and then all remaining circles and arcs (first stage of

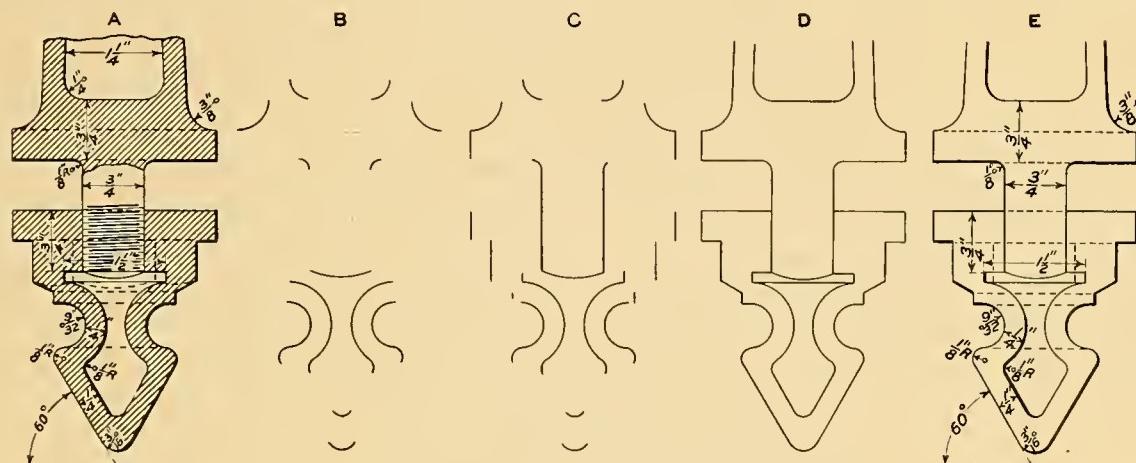


Fig. 57.

the inking). Next follows the inking of the perpendiculars, as shown in *C* (second stage); then (*D*), of all the horizontals and other remaining lines (third stage). The shade lines are added (*E*), the measurements are put in (*E*), and finally the drawing is cross-hatched and the broken lines are indicated, as in *A*.

In inking convergent lines (*A*, *B*, *C*, Fig. 58), to prevent them from running

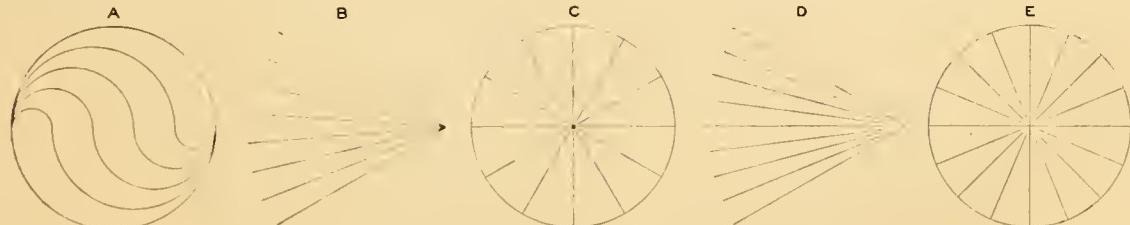


Fig. 58.

together near the point of convergence, let each line dry before inking another, and

carry the pen away from the point of convergence rather than towards it; or, terminate the interior lines (*D, E*, Fig. 58) at an arc described, in pencil, from the point of convergence taken as center.

Shade lines when drawn, should be added to the outer edges of straight and curved lines, so as not to encroach upon the surface of which the shade line is a boundary.

In the case of circles and circular arcs the shade line should be placed by shifting the center. Thus, for example, in drawing shade lines *mhk* and *egf*, Fig. 59, the center was shifted from *a* to *c*, a point in *dg*, the distance being determined by eye. It will be observed that the shade lines, as thus drawn, do not encroach on the surface included between the two circles. Likewise, shade line *stuv*, added to the outer edge of *st*, does not encroach upon the surface, *qrst*, of the ring.

**36. Lettering.** In connection with the study of mechanical drawing it is important to have extended practice in lettering and dimensioning (Art. 37).

(a) *Letter styles and sizes.* Figs. 60–67 (Plate 4) show letters and numerals — in two styles, sizes, and widths of line — to be used in rendering data and dimensions on the practice drawings. In lettering titles, the same styles should be used, but the letters should be larger. There should be lettered on the margin of all practice drawings the *title*,—as, for example, “Finished Plate 15,” “Study Plate 6,”—the *student’s name*, and the *date* when a drawing is completed. Heights for this lettering are given for two sizes of border-line (Fig. 70).

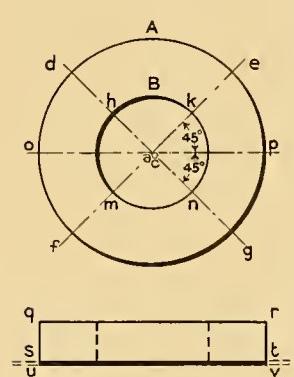


Fig. 59.

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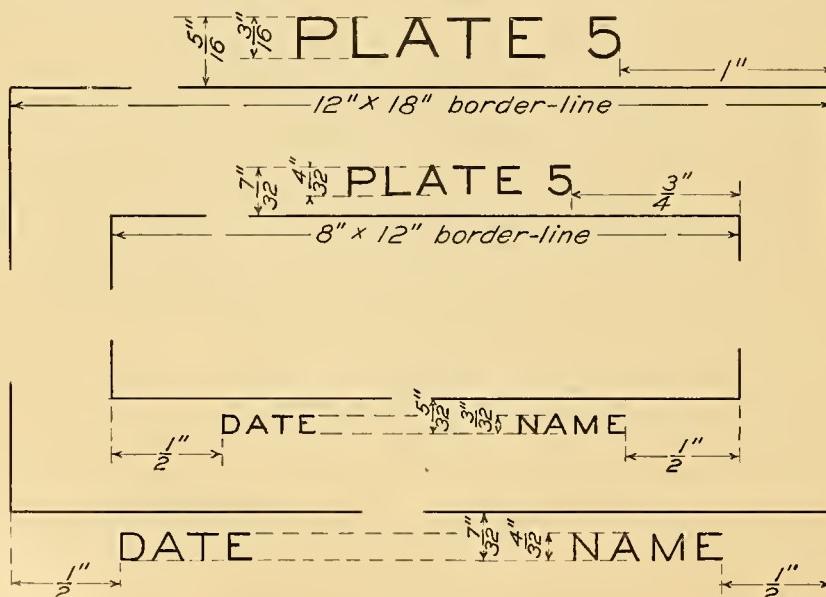


Fig. 70.

In general, drawings strong or heavy in appearance require a correspondingly

**Plate 4.**

ABCDEFGHIJKLMNPQRSTUVWXYZ  
1234567890& abcdefghijklmnopqrstuvwxyz  
Fig. 60.

ABCDEFGHIJKLMNPQRSTUVWXYZ  
1234567890& aabcdefghijklmnopqrstuvwxyz  
Fig. 61.

ABCDEFGHIJKLMNPQRSTUVWXYZ  
1234567890& abcdefghijklmnopqrstuvwxyz  
Fig. 62.

ABCDEFGHIJKLMNPQRSTUVWXYZ  
1234567890& aabcdefghijklmnopqrstuvwxyz  
Fig. 63.

ABCDEFGHIJKLMNPQRSTUVWXYZ  
1234567890& abcdefghijklmnopqrstuvwxyz  
Fig. 64.

ABCDEFGHIJKLMNPQRSTUVWXYZ  
1234567890& aabcdefghijklmnopqrstuvwxyz  
Fig. 65.

ABCDEFGHIJKLMNPQRSTUVWXYZ  
1234567890& abcdefghijklmnopqrstuvwxyz  
Fig. 66.

ABCDEFGHIJKLMNPQRSTUVWXYZ  
1234567890& aabcdefghijklmnopqrstuvwxyz  
Fig. 67.





heavy letter. If the general effect of a drawing is light — as in a geometrical construction — a light letter should be used (compare Figs. 60 and 62). In rendering dimensions and data having a line width corresponding to that in Fig. 63, the pen recommended is a Gillott's No. 303. In the case of working-drawings, letters and figures having a considerable width of line are demanded, as heavy as those in Fig. 60 or heavier, and the pen should be a ruling-pen ground for lettering (*c*, Art. 37), a coarse writing-pen, a ball-point, or a turned-point pen, the choice being a matter of personal preference.

(*b*) *Letter rendering; working-methods.* From the standpoint of common office practice, all reference letters and single dimensions should be rendered with strokes of the pen, as indicated in Fig. 68, and without the aid of guide-lines. The student should letter the practice drawings according to this method; and, to acquire proficiency, he should practice daily, according to Fig. 68, the letters and numerals given in Figs. 60–67, until he can make them with a reasonable degree of speed and uniformity. In the case of lines of letters or numerals, one guide- or base-line may be drawn. It will be seen that (Fig. 69) the center-line of a fraction, whether vertical or inclined, should bisect the numerator and the denominator.

(*c*) *Letter rendering with the ruling-pen.* An example of rapid-stroke lettering executed with the ruling-pen is given in Fig. 71. The cut is half the size

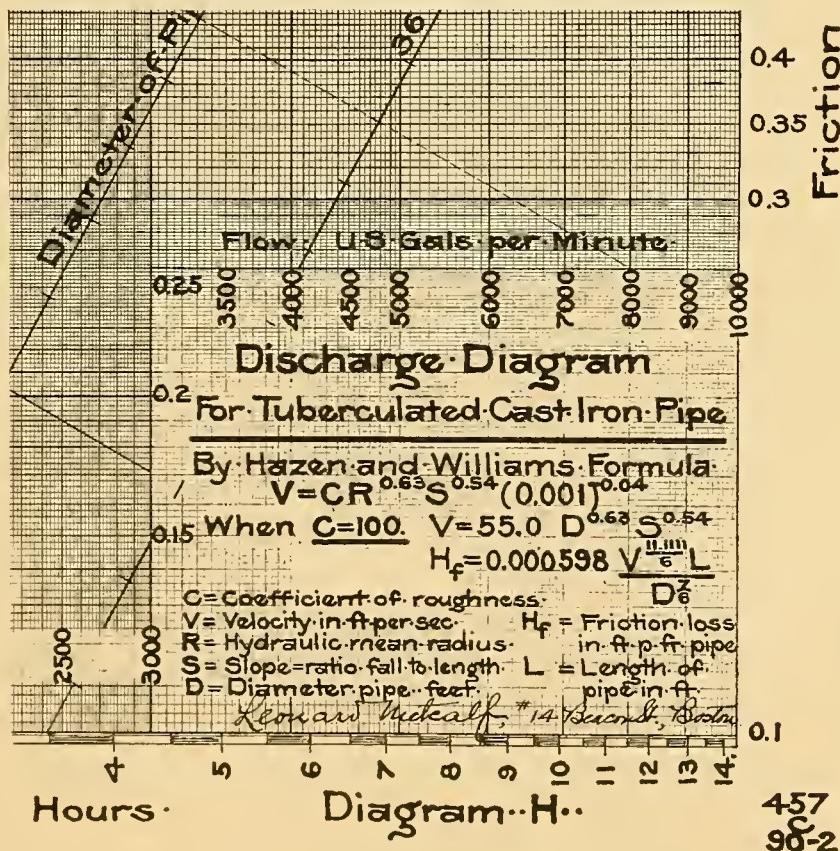


Fig. 71.

of the original, which was taken at random from a large number of office drawings equally well lettered, and in a like manner.

The special advantage in using the ruling-pen is the increase obtainable in the size of the letter and in its line width. As to the pen, an inexpensive or an old one is sufficiently good for the purpose. To form the point, hold the pen perpendicular to the oil-stone, and grind until the point is very blunt. Next hold the pen as in Fig. 51, and grind until the general figure of the two blades, taken together, is approximately conical, except at the point, which should remain blunt. Finally, starting with the pen held perpendicular to the stone, carry its point in a circular path, meanwhile constantly changing the general direction of the pen from the perpendicular, to take all possible angles between the perpendicular and  $45^\circ$  with the stone — a movement which changes the roughly blunted point to one having a spherical shape.

To letter with the pen, hold it at an angle between  $45^\circ$  and  $60^\circ$  with the paper, with the thumb resting on the head of the regulating screw, which should be horizontal. It is best to fill the pen with the common writing-pen, or a quill, as wiping is likely to draw too much ink from between the blades.

**37. Dimensioning.** This term signifies the giving of measurements on drawings (Fig. 72), and includes the rendering of the numerals, their arrangement

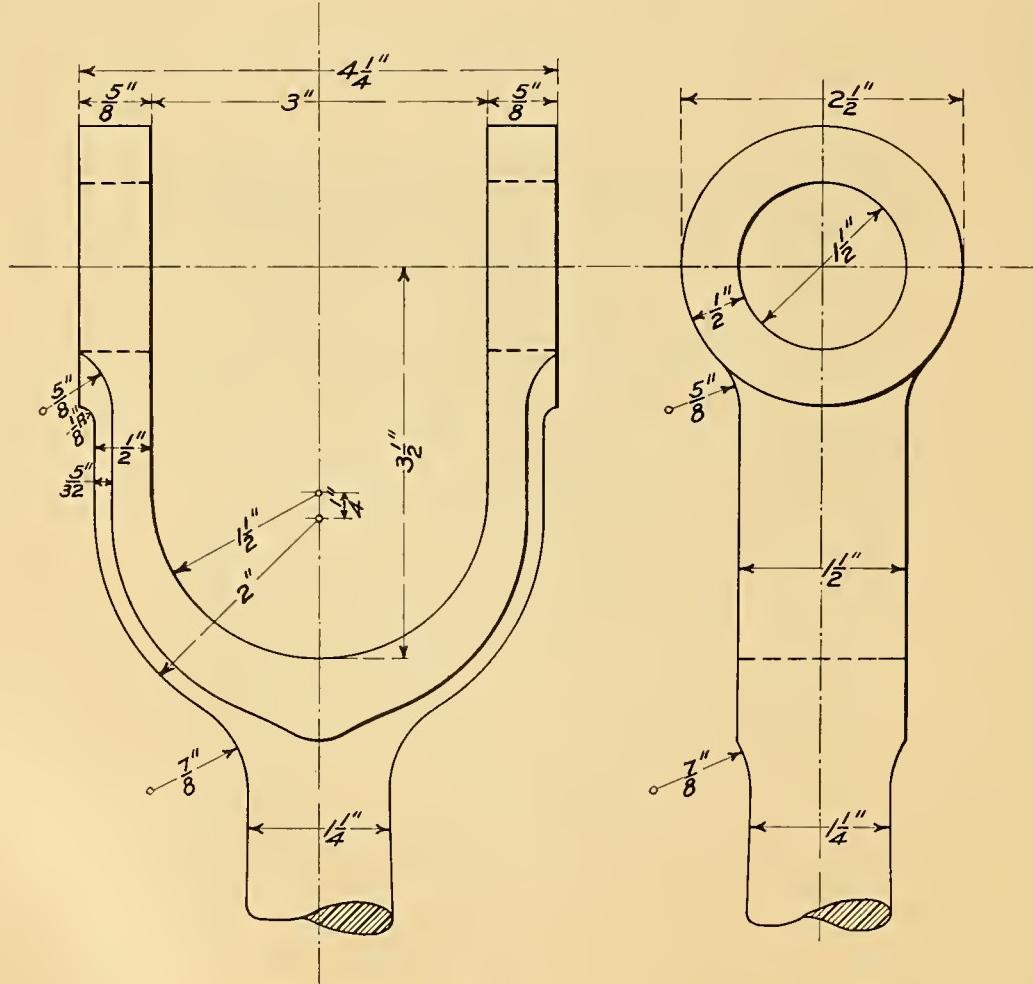


Fig. 72.

on the drawing, and the selection of their size and style. A *dimension line* is one

drawn from a measurement to the arrow-heads indicating the points of measurement. *Extension lines*—see the vertical lines composed of short dashes, Fig. 72—are used in case of interference or confusion, to carry points of measurement to another part of the drawing. The sign ' means feet, and the sign " means inches: thus  $10'$ — $6\frac{1}{2}''$  is read ten feet, six and one-half inches. The quantities feet and inches should always be separated by a dash (Fig. 69, Plate 4). Line widths and lengths of dashes for both dimension and extension lines are given in Fig. 54. Average-sized numerals, to be used in dimensioning the practice drawings, together with the proper form of arrow-heads, are given in Fig. 69, Plate 4.

## STUDY PLATE I.

For practice in the accurate use of the T-square, triangles, scale, pricker, and ruling-pen.

Size of the plate, when trimmed, to be  $14'' \times 20''$ , with a  $1''$  margin. Use Whatman's hot-pressed paper.

*Penciling.* Sharpen the 6H pencil to a ruling-point (*a*, Art. 23). Make all the lines *full*, very narrow and light, but distinct. Lay out a  $12'' \times 18''$  border-line; work from the upper and left-hand edges of the paper (*d*, Art. 24). For location and other measurements, see Plate 5.

(*a*) Locate, and rule with the T-square, the horizontal lines, Fig. *A*, Plate 5; start each of these lines at a vertical line (*KL*, Fig. 73) drawn  $1\frac{1}{8}''$  from the left-hand side of the border-line. Using the scale and the pricker, lay off accurately (*b*, Art. 29), as many times as the length of each line will permit, the following measurements: on line *A*,  $\frac{7}{8}''$ ; on *B*,  $\frac{7}{16}''$ ; *C*,  $\frac{7}{32}''$ ; *D*,  $\frac{3}{4}''$ ; *E*,  $\frac{3}{8}''$ ; *F*,  $\frac{3}{16}''$ ; *G*,  $\frac{3}{32}''$ . On line *H* lay off in succession  $\frac{9}{32}''$ ,  $\frac{15}{32}''$ ,  $\frac{3}{16}''$ ,  $\frac{9}{16}''$ ,  $\frac{3}{8}''$ ,  $\frac{21}{32}''$ , and  $\frac{9}{16}''$ . In laying off the measurements on each line, *do not move the scale*. *Test.* Using T-square and triangle, drop a perpendicular, as *ac*, Fig. 73, from each point of measurement in line *A*. See whether each perpendicular passes through the imaginary center of each alternate division, in line *B*, as point *b*; also, whether each perpendicular from line *A* passes through every fourth point, as *c*, in line *C*. Continue the test as shown by Fig. 73.

(*b*) With the triangle placed against the T-square, rule the perpendiculars, Fig. *B*, Plate 5.

(*c*) Draw the rectangles, Fig. *C*, to the scales indicated.

(*d*) Locate point *A* in Figs. *D*, *E*, *H*, and *J*, and point *B* in Figs. *F* and *G*.

Through these points draw, indefinite in length, the vertical and horizontal lines.

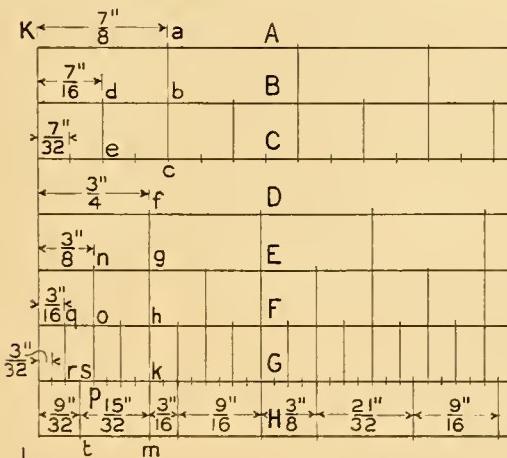


FIG. 73.

Rule the equally spaced parallel lines, making the angles of  $45^\circ$ ,  $60^\circ$ , and  $30^\circ$  with the horizontal. In each case the spaces must be laid off at right angles to the required lines (see Fig. 27).

(e) Draw the line  $AB$ , Fig.  $K$ , and locate point  $C$ . Using two triangles, draw the equally spaced lines parallel to  $AB$  ( $d$ , Art. 26). Rule the lines perpendicular to  $AB$  (see  $B$ , Fig. 30) and lay off their length. Rule the lines drawn from points  $E$  and  $F$  (see Fig. 30); terminate the lines by circular arcs, as shown in Fig.  $K$ .

(f) Using the T-square and  $30^\circ$ - $60^\circ$  triangle, draw Figs.  $L$  and  $M$ . *Test.* In Fig.  $L$ , with the  $30^\circ$ - $60^\circ$  triangle placed against the T-square, bisect the angles, and see if the bisectors intersect in the same point. In Fig.  $M$ , with the  $45^\circ$  triangle placed against the T-square, draw the diagonals of the square, upward from the ends of the base, and see if each passes accurately through an upper corner of the square.

(g) Begin Figs.  $N$  and  $O$  by repeating Figs.  $L$  and  $M$ . Find, by scale measurement, the middle point of each side of the triangle (Fig.  $N$ ) and draw  $CD$ ,  $BD$ , and  $AD$ , respectively perpendicular to a side of the triangle. Lay off on each perpendicular the measurements given on  $BD$ . Through these points, using T-square and triangle, draw the sides of the interior triangles. *Test.* Produce  $CD$ ,  $BD$ , and  $AD$ , and see if the alignments of the corners of the triangles are accurate.

Find by scale measurement the centers  $C$  and  $B$  of two sides of the square (Fig.  $O$ ). Draw the diameters,  $CD$  and  $AB$ , of the square. On each semi-diameter lay off the measurements given at  $C$ . Through these points draw the sides of the interior squares. *Test.* Draw the diagonals of the outer square and see if they pass through the center of the square, as located by the diameters, and also if they pass through the corners of the inner squares.

(h) Draw the hexagon, Fig.  $P$ , according to the given angles and measurement. *Test.* Connect the opposite angles of the hexagon and see if the diagonals thus obtained intersect in the same point.

(i) Draw  $AB$ , Fig.  $Q$ . Using T-square and triangle, complete the hexagon without further scale measurement. *Test.* Measure with the scale each side of the hexagon, and see if all have the same length.

(j) Having finished the penciling, the drawing is now to be used as the preliminary for a tracing, after which it is to be finished in ink. In general, if a drawing is made for a tracing, all lettering and dimensions should be suggested before the tracing is begun; but, when a drawing is required to be finished in ink, the lettering may follow the inking. In the present case the lettering and dimensions should now be indicated in pencil, but, in view of the second use of the drawing, with greater accuracy and neatness than might be required for a tracing.

Take as a guide Figs. 60 and 65, (Plate 4). Show all lettering and dimensions given on Plate 5; suggest also the title "Study Plate 1," your name, and the date, according to the measurements given in Fig. 70. In the case of single

letters and lines of letters, rule only *one* guide line, above which the letters are to be placed. Suggest quickly and lightly the general position, quantity, form, and spacing of the letters. In the case of each dimension, rule first, if required, the extension lines \* (Art. 37); next rule the dimension line (Art. 37); then indicate the arrow-heads; and last, suggest the position and size of the numerals. *Work rapidly.*

*Tracing.* Work on the dull surface of the tracing-cloth. Smooth out the cloth as flat as possible, and fasten with four additional thumb-tacks placed midway between the corners. See that the ink is *black*. If the cloth does not take the ink well, use chalk (Art. 32). The lines made on the tracing-cloth should cover the lines in pencil accurately.

(k) Make the lines *A—H* (Fig. *A*) full, and of the width given in *A*, Fig. 54. Indicate the scale measurements laid off on lines *A—H*, in the pencil-drawing, by ruling through the center of each point of division a very narrow line perpendicular to and extending about  $\frac{1}{16}$ " above and below the given line. Make each line in Group *J* (Fig. *A*) the same as the corresponding line in *D—J*, Fig. 54; repeat for Fig. *B*. In the remaining figures make all result lines the same as the line *D* (Fig. 54); make incidental lines, as *AB*, Figs. *D—J* (Plate 5), like *A* or *B* (Fig. 54). The line of the ruled border should be slightly wider than the result lines in the drawing. *Test.* Measure with the scale the distances on lines *A—H*, Fig. *A*, as established in the tracing; see if they correspond with the measurements given in Fig. 73.

(l) Render, directly in ink, with strokes of the pen (*b*, Art. 36), the lettering, dimensions, and signs for inches. Rule the dimension lines; put in the extension lines; and render the arrow-heads.

(m) Erase and redraw the lines radiating from *F*, Fig. *K* (*c*, Art. 33); use erasing shields (*b*, Art. 33) to protect the lettering, erased portions of which should be restored.

*Inking the pencil-drawing.* (n) Proceed according to the instructions in *k*, *l*, and *m* (*Tracing*), except as follows: Make all lines in the drawing like line *A*, Fig. 54. Take for a guide in the lettering and dimensioning, Figs. 62 and 67. The title, "Study Plate 1"—on account of the size of the letters—may be *drawn* (free-hand) instead of stroke-rendered.

(o) Erase and redraw Fig. *O* (*b*, Art. 33).

(p) Erase pencil-lines. *Do not roll the drawing.*

#### STUDY PLATE 2.

For practice in the accurate use of the compass, dividers, and French curve.

Use Whatman's hot-pressed paper. The ruled border-line is to be 12<sup>11</sup> x 18<sup>11</sup>, with a 1" margin. Use the 611 pencil. For location and other measurements see Plate 6.

\* In preliminary penciling the dimension and extension lines should be drawn in full line.

*Penciling.* (a) Make all lines *full*, very narrow, and light, but distinct. Describe the circle *A*, Fig. *A*. Rule a line from the center to the circumference, and on this line lay off the spacing of the interior circles, the smallest of which is  $\frac{1}{8}$ " diameter; describe the circles, according to *a*, Art. 27. From the same center, using the lengthening bar (*b*, Art. 27), draw the arcs, Fig. *C*.

(b) Work the following steps very accurately. Draw *AB*, Fig. *B*, and locate the center *C*, by scale measurement. Using only the T-square and the  $30^\circ$ - $60^\circ$  triangle placed against the T-square, draw the hexagon, its diameters, and its diagonals. Distant  $\frac{5}{8}$ " from *A*, locate point *H*, and, with *C* as center, describe the circle *OHK*. With  $\frac{5}{8}$ " radius, centers on circle *OHK*, describe the circles tangent to the sides of the hexagon. Establish the points of tangency, as *P*, *Q*, and *R*, by drawing, with *C* as center, the circle through point *P*, which is the intersection of *HK* and *CT*. *Tests.* With *C* as center, radius *CA*, describe a circle; see if the imaginary center lines of the three tangent lines at *A*, *G*, *E*, *B*, *F*, and *D*, intersect in a point (Fig. 42). With  $\frac{5}{8}$ " radius, *C* as center, draw a circle; see if, in its intersection with each diameter of the hexagon, it is tangent to each of the six equal circles. If the results in the foregoing constructions are found to be inaccurate, all lines should be erased, the line *AB* moved  $\frac{1}{8}$ " to the left, and the construction repeated.

(c) From line *LH*, indefinite in length, draw lines *A*—*F*, Fig. *D*. With the hair-spring dividers, and according to *a* and *b*, Art. 30, space the lines into equal parts, as follows: *D*, 17 parts; *B*, 13; *C*, 11. With the bow-spacers divide equally as follows: *A* into 17 parts; *E*, 13; *F*, 11. *Test.* Locate point *L* by producing line *JK*. Draw through point *L* a straight line from each point of division on line *D*. See if the line from each of these points passes through the corresponding point of division in line *A*. Test in like manner the points of division in lines *B* and *E* and in lines *C* and *F*.

(d) Draw, Fig. *E*, the circles, circular arcs, and line *EM*. With the hair-spring dividers, and starting at line *EM*, space the circles *A* and *B* each into 19 equal parts. With the bow-spacers, starting at line *EM*, divide circles *C* and *D* each into 19 equal parts. *Test.* Draw very accurately from center *E* to each point of division in circle *A*; see if each line passes through the centers of the corresponding divisions in circles *B*, *C*, and *D*.

Draw *EG* through point 14, Fig. *E*. With the hair-spring dividers space equally arc *HN* into 5 parts; *JO* and *LQ* each into 9; *KP* and *MG* each into 7 parts. *Tests.* Draw from center *E*, through points 15, 16, 17, and 18, circle *A*; see if these lines produced pass through the centers of the points of division in arc *HN*. From center *E* draw through the points of division in *JO*, and produce the lines to intersect *LQ*; see if the lines pass through the centers of the points of division in *LQ*. From center *E* draw through the points of division in *MG*; see if the lines pass through the centers of the points of division in *KP*.

(e) The curves *A*—*J*, Fig. *F*, are to be located by pricking through the curves

given in Plate 7, and the points thus obtained are to be connected free-hand (*a*, Art. 28). To prick off the points, proceed as follows: Draw a short perpendicular across the lower horizontal line of the ruled border-line, 6<sup>11</sup> from its right-hand end. Cut holes through Plate 7, one hole at each end of line *AB*, and one on *ab*. Now tack this plate over the drawing, taking care not to press the thumb-tacks through the drawing or its margin; place *AB* over the ruled border-line, and *ab* on the perpendicular located 6<sup>11</sup> from the corner of the border-line. The location and the number of the points to be pricked through must be determined by judgment aided by the following suggestions. In the sharp curves at the ends of curve *F* (Plate 6) take the points from  $\frac{1}{3}\frac{1}{2}$ <sup>11</sup> to  $\frac{1}{16}$ <sup>11</sup> apart, and, for the flattest portions of the same curve, from  $\frac{1}{4}$ <sup>11</sup> to  $\frac{3}{8}$ <sup>11</sup> apart. The points at the ends of curve *A* (Plate 6) should be from  $\frac{1}{8}$ <sup>11</sup> to  $\frac{3}{16}$ <sup>11</sup> apart. In the ellipses the ends of both axes should be pricked through and the axes ruled before sketching in the curve.

(*f*) Indicate the lettering and dimensions given in Plate 6, and also the title "Study Plate 2," your name, and the date (see *j*, Study Plate 1). Note that, as in Study Plate 1, the present drawing is to be traced, after which it is to be regarded as the first stage of a finished drawing in ink.

*Tracing.* (*g*) Trace the drawing accurately. Ink in the circles *A*—*F*, Fig. *A*, to correspond to the lines *A*—*F*, Fig. 54. Repeat for circles *G*—*M*, Fig. *A*. Make the two remaining circles like line *A*, Fig. 54. Ink in the arcs *A*—*F*, Fig. *C*, to correspond to the lines *A*—*F*, Fig. 54. In the remaining figures ink in the result lines, like line *D*, Fig. 54, and make the incidental lines, like line *A*, Fig. 54. Omit the lines used in the tests. Indicate the points of division obtained in the spacing by a short line perpendicular to the divided line, whether circular or straight, as directed in *k*, Study Plate 1. The line of the ruled border should be slightly wider than the result lines in the drawing.

(*h*) Render the lettering, dimensions, dimension and extension lines, signs, and arrow-heads according to *j*, Study Plate 1.

(*i*) Erase and redraw ellipse *D*, Fig. *F* (*c*, Art. 33).

*Inking the pencil-drawing.* (*j*) Proceed according to *g* (*Tracing, Study Plate 2*), except as follows: In Figs. *B*, *D*, *E*, and *F*, make all the lines of the width *A*, Fig. 54. In inking the curves, *A*—*J*, proceed strictly according to the instructions given in *a*, Art. 28; if strictly accurate results cannot be obtained, with the French curves available, templates should be made (*b*, Art. 28). Ink the axes of the ellipses, and all lines used in the tests, full, very narrow, and in *red*. Take for a guide in the lettering and dimensions Figs. 62 and 67. The title "Study Plate 2" should be drawn instead of stroke-rendered.

(*k*) Erase and redraw *F*, Fig. *F* (*b*, Art. 33).

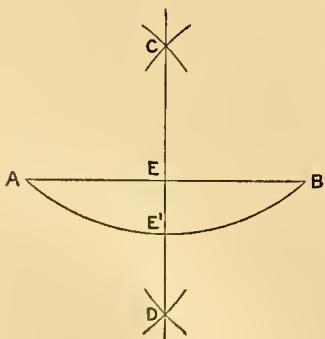
(*l*) Erase pencil-lines. *Do not roll the drawing.*

## CHAPTER III.

## GEOMETRICAL CONSTRUCTION.

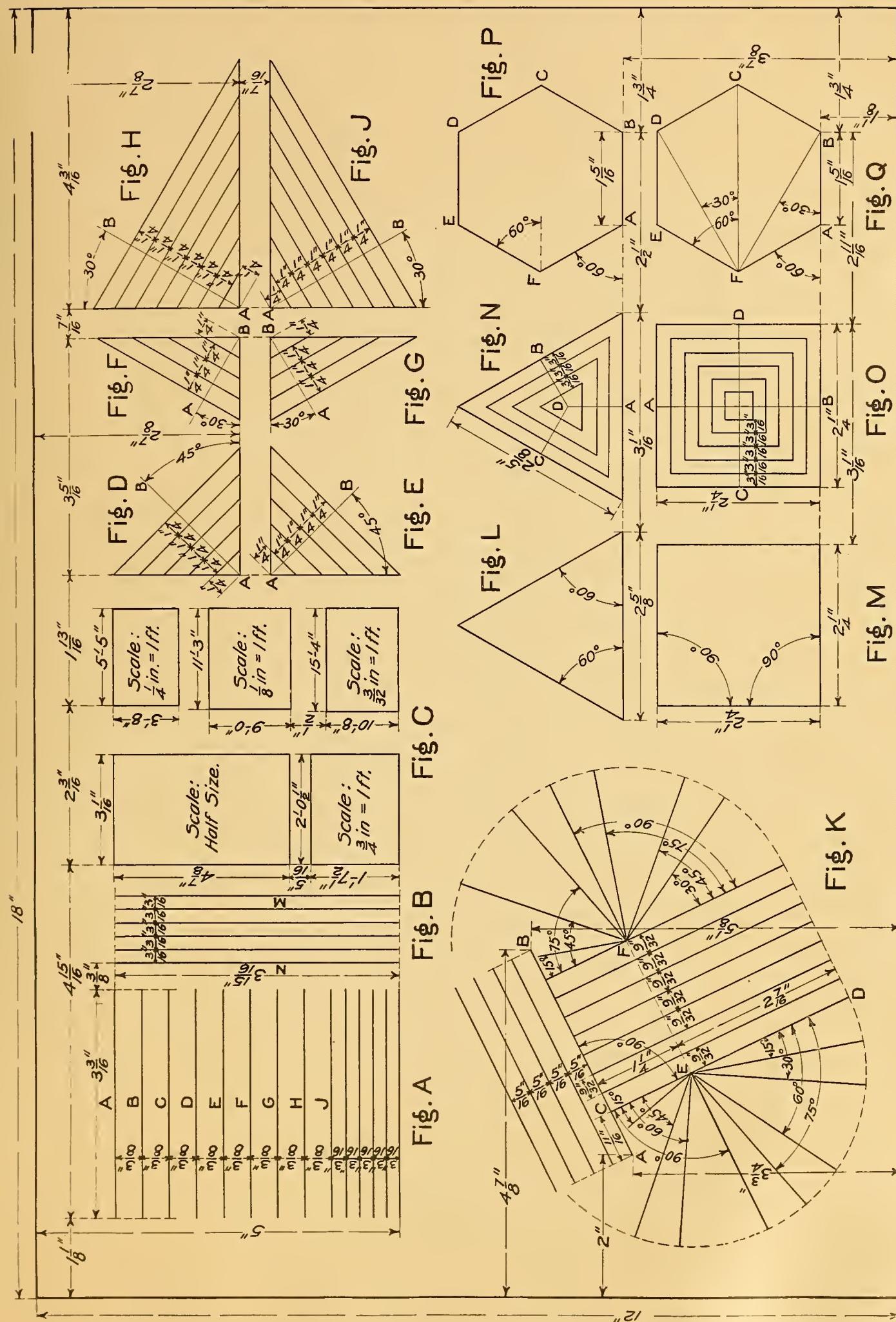
The following problems are given for further practice in precise rendering and for their application in practical drawing. As to application, it should be understood that the use of such problems is not necessarily confined to the drawing-room or to drawings of the usual sizes. The mechanic, for example, may need to work out a geometrical construction to the actual size of the work in hand, on wood, metal, or on the floor of the shop, and in large work substituting chalk-line for straight-edge, and striking the arcs with a piece of chalk held at the end of a string or strip of wood swung from a nail as a center. Likewise, we may see the landscape gardener laying out a problem directly on the ground, stretching the tape for a straight-edge and describing arcs with aid of tape and measuring pins.

In the precise rendering of problems the student should continue to hold himself to the strict observance of details concerning the condition of his instruments and their handling. In penciling, all lines should be drawn with a 6H pencil, *full*, and as narrow as possible. Lines required to meet in a given point, as at the corners of a polygon, and lines drawn to a point determined by intersecting lines, should not stop at the point but should be drawn *through* it. When the extremity of a line is used in measuring, as a center for the compass, or otherwise, it should be definitely located, either with the pricker or by a shortruled line drawn at right angles to the given line. Intersecting arcs, for appearance, should be made of equal length, and for accuracy should be placed as nearly at right angles as possible. For greater accuracy, every point required to be used as a center for the compass should be noted with the pricker before placing the needle point of the compass; this is especially necessary if the paper has a grained surface, since the inequalities of the surface are more likely to deflect, unobserved, the needle point of the compass than that of the pricker. In inking, unless otherwise directed, all lines should be made *full*, of the same width, and as narrow as possible without sacrificing quality of line. Given lines may be drawn in blue, construction lines in red, and result lines in black.



**Problem 1.**—To bisect a straight line, as  $AB$ , or a circular arc, as  $AE'B$ . With any appropriate radius,  $A$  and  $B$  as centers, describe arcs intersecting in  $C$  and  $D$ . Draw  $CD$ .  $E$  and  $E'$  are the required middle points.

Plate 5.





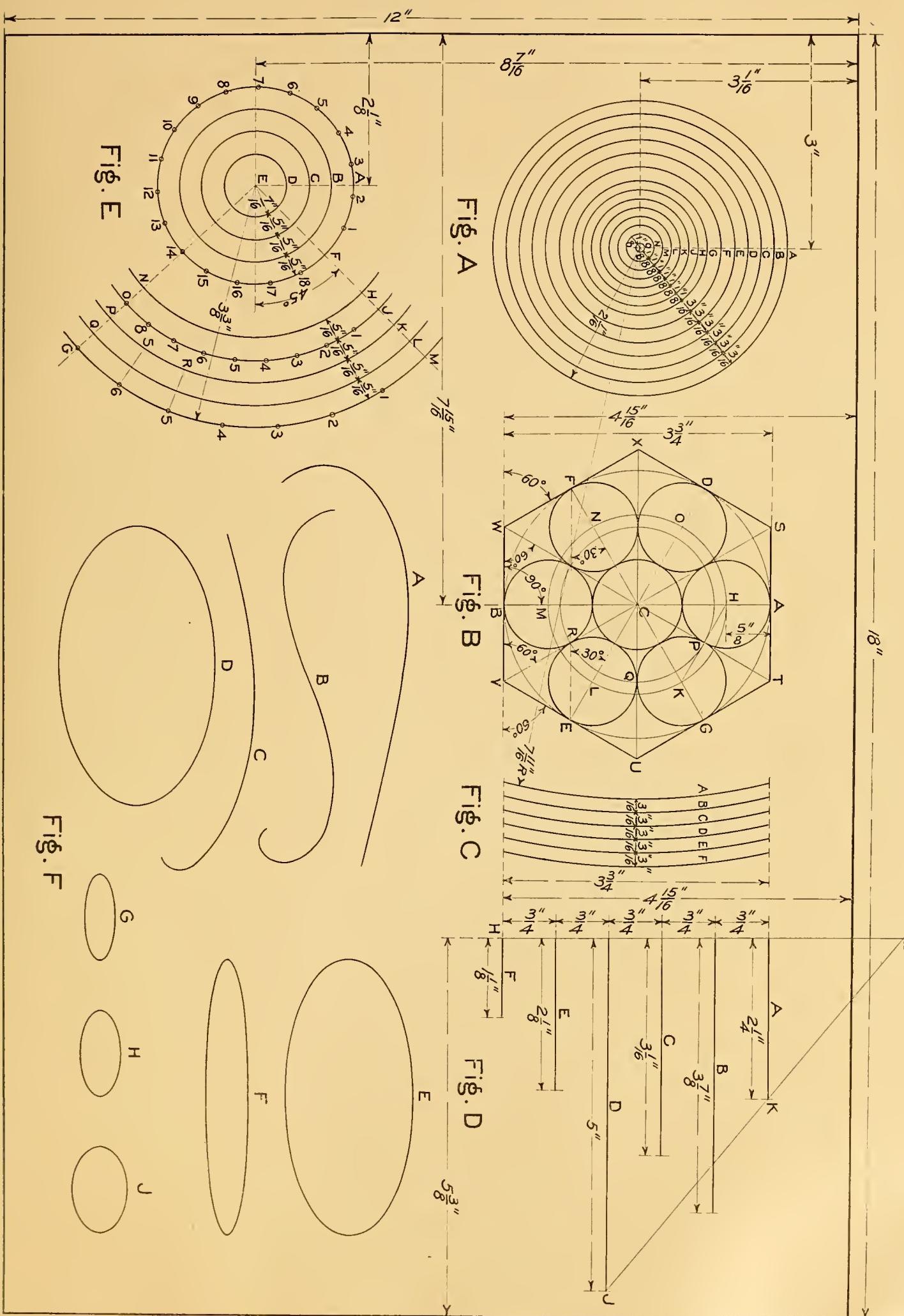
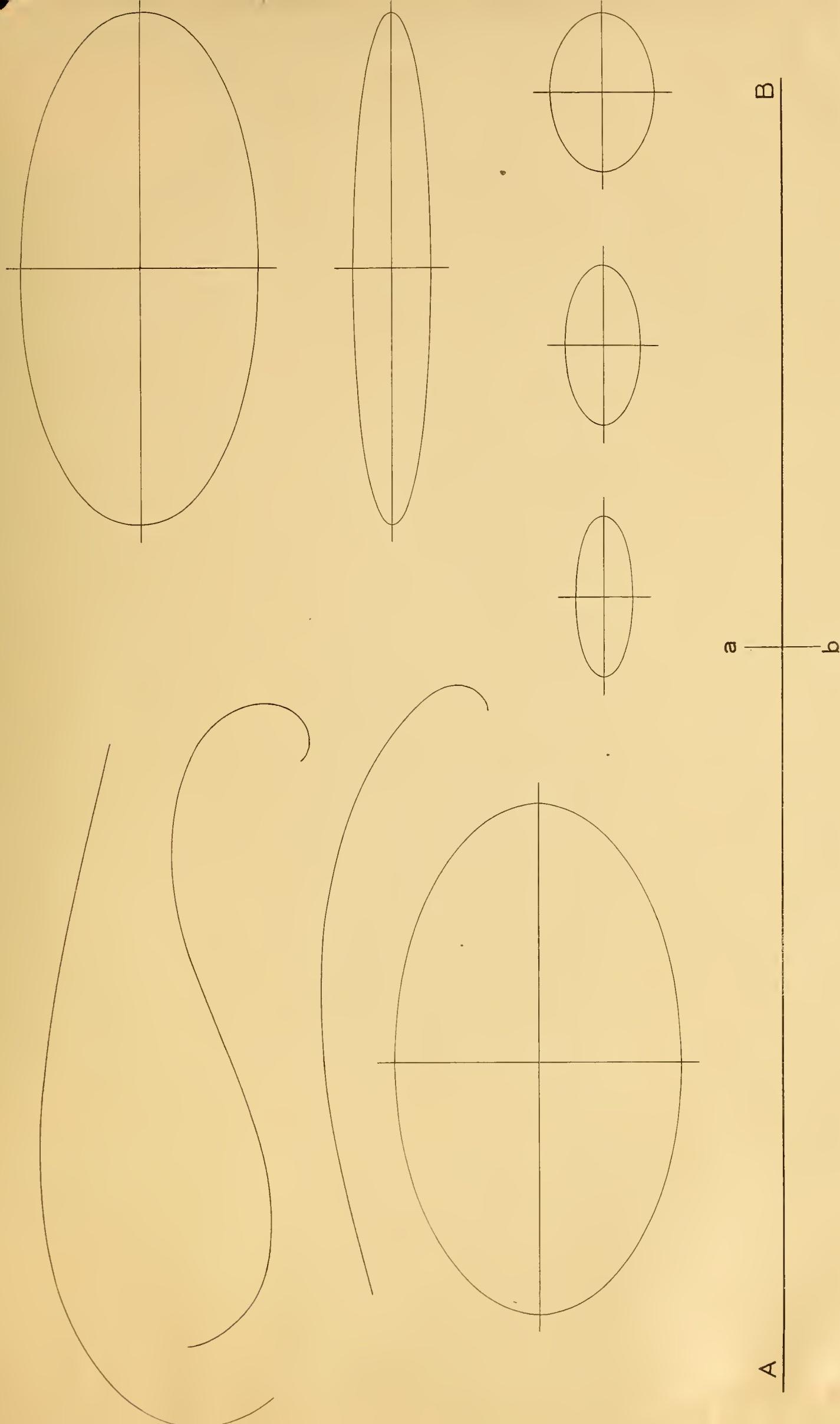




Plate 7.



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